LowCVP
Low Carbon Vehicle Partnership

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Transport Energy Infrastructure Roadmap to 2050

METHANE ROADMAP

Prepared for the LowCVP by Element Energy Ltd
Celine Cluzel & Alastair Hope–Morley

elementenergy

JUNE 2015





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Project Steering Group
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BOC Limited
BEAMA
Calor Gas Ltd
EDF Energy
Electricity Networks Association
National Grid
Office for Low Emission Vehicles
Renewable Energy Association
Transport for London
Transport Scotland
UK Petroleum Association

Acknowledgements

The LowCVP, established in 2003, is a **public-private partnership** that exists to **accelerate a sustainable shift to lower carbon vehicles and fuels** and create opportunities for UK business.

The LowCVP aims to:

- Develop initiatives to promote the sale and supply of low carbon vehicles and fuels
- Provide input and advice on Government policy
- Provide a forum for stakeholders to share knowledge and information
- Ensure that UK motor, fuel and related businesses are best placed to capitalise on the opportunities in the low carbon markets of the future
- Contribute to the achievement of UK Government targets for road transport carbon reduction

Project Steering Committee

Autogas Limited
BOC Limited
BEAMA
Calor Gas Ltd
EDF Energy
Electricity Networks Association
National Grid
Office for Low Emission Vehicles
Renewable Energy Association
Transport for London
Transport Scotland
UK Petroleum Association

Workshop attendees

Aberdeen City Council
Air Products
BRC
BYD
Calor gas
CNG Fuels
CNG Services
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Downstream Fuel Association
Drivelectric Ltd.
ENN Group Europe
Gas Bus Alliance
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UKPN
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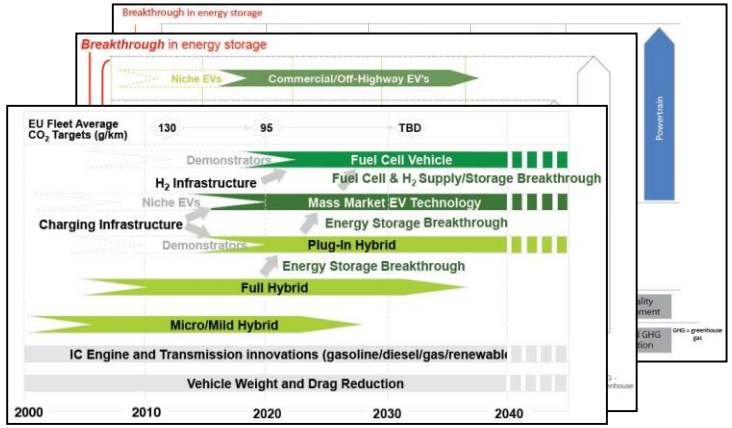
UPS
Wales & West Utilities

Contents

Background - a 'Transport Infrastructure roadmap' is needed to complement existing vehicle and fuel roadmaps

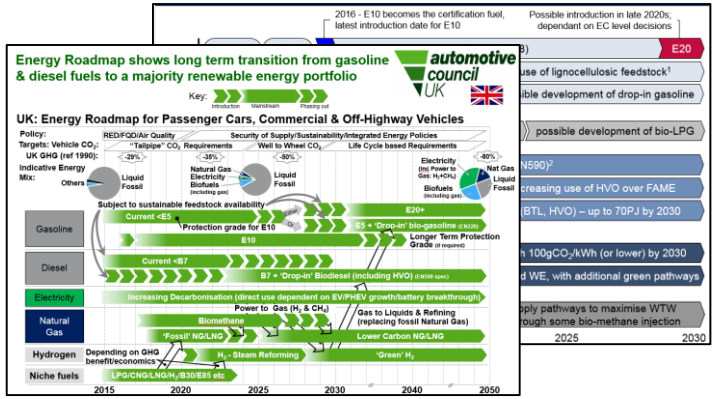
- In the context of the expected transition to lower carbon powertrains and fuels, the **Auto Council vehicle roadmaps** have proven to be a useful tool **to focus research, funding and policy**, bringing into one place the industry's views on future technology options, deployment steps and corresponding policy drivers.
- To complement these powertrain technologies roadmaps, the **LowCVP commissioned a Road Transport Fuels Roadmap in 2013-14**, which also proved successful in bringing clarity to the fuel options available and mapping the enabling milestones.
- This Infrastructure roadmap is the 'missing piece' that will support new powertrains and new fuels. This roadmap is all the more necessary as the **needs and barriers for deployment of electric, hydrogen and gas refuelling stations differ significantly** and refuelling/recharging infrastructure is a key enabler for low emission vehicles.
- The objectives of the Infrastructure Roadmap are to:
  - **Assess the infrastructure needs** and barriers for deployment of electric, hydrogen and gas refuelling stations to 2050, including impact on upstream distribution, as well as to consider 'conventional' liquid fuels
  - Make **recommendations for delivery** of infrastructure deployment, both at national and local government level.

Vehicle roadmaps



Source: Auto Council and LowCVP

Transport fuel roadmaps



Source: Auto Council and Element Energy for the LowCVP

Source: Element Energy

The Infrastructure Roadmap covers private and public infrastructure, for all main road vehicles and both current and future fuels

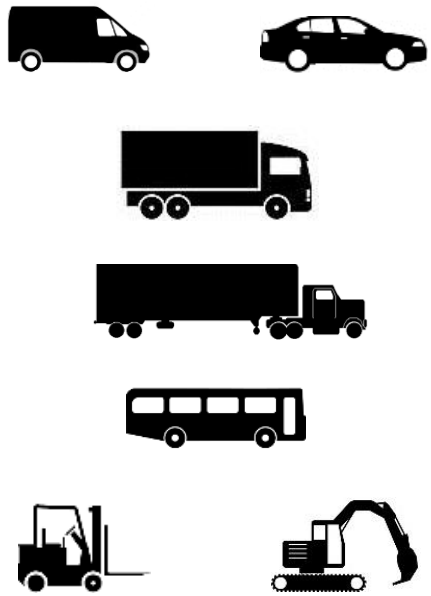
Fuels / energy vectors considered

- Zero tailpipe emission fuels: **electricity and hydrogen**
- 'Conventional' **liquid fuels**: gasoline (E5 to E20, in line with the Transport Fuels Roadmap), diesel, LPG/bio-propane
- **Methane**: Compressed Natural Gas (CNG), Liquefied NG (LNG) and biomethane
- Niche/future fuels: methanol, liquid air and a high bioethanol blend (E85)

Refuelling infrastructure types

- Depot based refuelling for fleet operators and return to base operators
- Home recharging for private and (some) commercial vehicles
- Public forecourt refuelling/recharging

Vehicle types



Drivers for change in the transport energy system

- The UK's legally binding target to **reduce total GHG emissions by at least 80% (relative to 1990 levels) by 2050**, and transport contributes to c. 25% of UK total GHG emissions;
- EU level regulations (gCO_2/km, **Air Quality targets** and EURO spec), Directives (Renewable Energy, Fuel Quality, Clean Power for Transport) and Transport White Paper

Source: Element Energy

The development of the Infrastructure Roadmap benefitted from input from a wide range of stakeholders, many consulted through workshops

Develop uptake scenarios for % sales of electric and ICE vehicles

ICE vehicles: diesel, petrol, LPG, gas vehicles
Electric vehicles: Battery (BEV), Plug-in Hybrid (PHEV), Range-Extended (RE-EV) and hydrogen fuel cell (FCEV)
Niche/future fuels considered: E85, methanol, liquid air

Input into Element Energy fleet model

Scrappage rate, stock and mileage inputs based on **DfT data/projections: c. 40% increase in stock and vkt by 2050 (39 million vehicles, 740 billion vkt)**; Vehicle efficiency based on **Committee on Climate Change modelling**

Output numbers of vehicles in the fleet and MJ used per energy vector

See full reports for further details of fuel uptake scenarios

Review existing literature on refuelling and upstream infrastructure

Industry consultation with LowCVP Fuels working group

Prepare Infrastructure Roadmap

Four dedicated fuel workshops were conducted

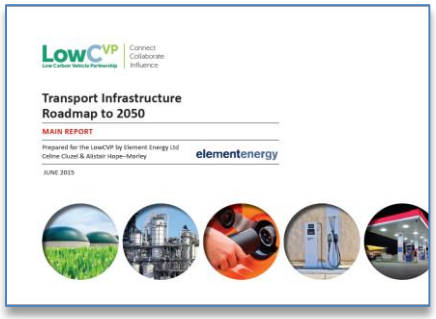
- Workshop themes: **electricity, liquid fuels, methane, hydrogen**
- **38 attendees included**: Infrastructure manufacturers, installers, operators, DNOs, energy companies, fuel suppliers, OEM / vehicle suppliers, end users, local government / regulator

Host stakeholder workshops

Review by Steering Committee

Prepare draft report

Complete final report



Report preparation

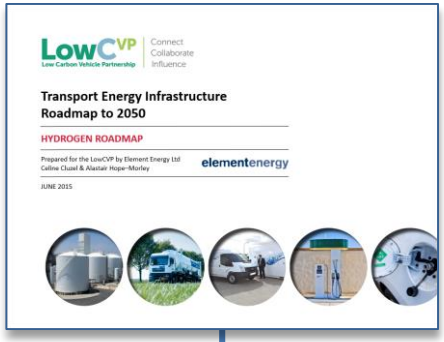
External input

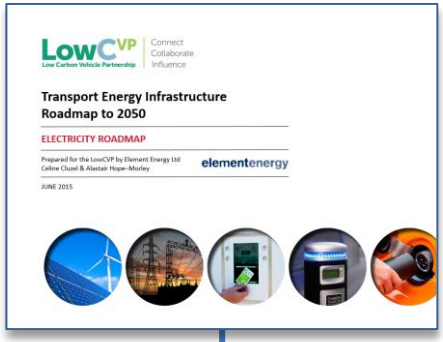
Source: Element Energy

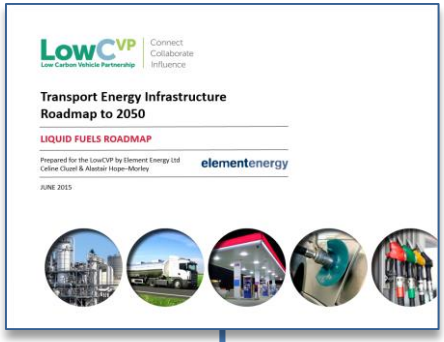
vkt: vehicle km travelled

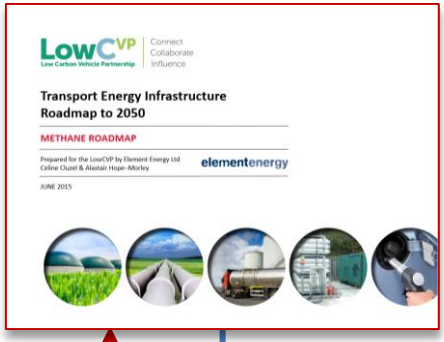
Four separate reports have been developed – this report is dedicated to the case of methane as a transport fuel

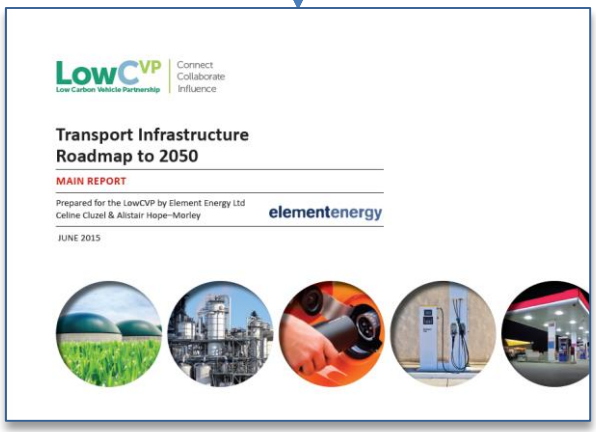
Four separate reports were produced to capture the differences between the energy vectors / fuels under consideration











This report

Final report summarising findings from each energy vectors

Structure of the report

- **Background and status quo**
  - Summary of current transmission & distribution system and energy vector usage
  - Energy vector current supply pathways
  - Current dispensing technologies, geographical spread and key stakeholders

- **Future infrastructure requirements and barriers to deployment**
  - Quantification of gas refuelling station needs, per location and/or vehicle segments - based on projected demand, derived from validated uptake scenarios
  - Barriers to deployment of infrastructure - *barriers to deployment of corresponding powertrains are not discussed– uptake of new powertrains/fuels is the starting assumption*
  - Impact on distribution / transmission systems

- **Summary: infrastructure roadmap and recommendations**
  - Roadmap schematic that summarises the above findings
  - Recommendations for delivery (national, local, RD&D needs, funding shortfall)

Contents

The extensive natural gas supply chain in the UK can support the development of natural gas refuelling infrastructure

methane

Upstream

Midstream

Downstream

Unprocessed natural gas

Natural gas

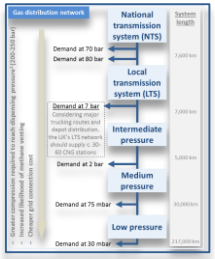
LNG

(Gaseous) natural gas flow

LNG flow

Gas processing terminal

Coastal import terminals



See schematic of natural gas grid in upcoming section

Natural gas grid

LNG is distributed via trucks or vaporised at import terminals and injected into the gas grid

Extensive coverage: c. 270,000 km of pipeline
Multiple pressure points: 30 mbar – 85 bar

>>99% of UK total natural gas consumption

<<1% of UK total natural gas consumption

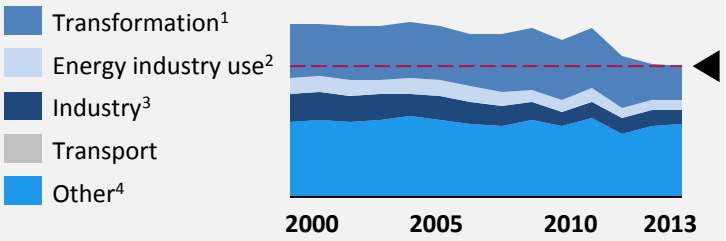
Non-transport demand[1]

Transport demand

Private depots

Public forecourts

Annual total UK natural gas consumption



844 TWh (2013)

SOURCE: DUKES Chapter 4 (2015). [1]Includes electricity generation and heat generation, [2]Oil, gas and coal extraction, refineries, etc. [3]Iron and steel, petrochemicals, mineral products, food/beverages, etc. [4]domestic, commercial, public sector, agriculture

Methane (CH_4) as a transport fuel is commonly dispensed to end users in two forms; as Compressed Natural Gas or Liquefied Natural Gas

Liquefied Natural Gas (LNG) $CH_{4(l)}$

Key characteristics

a. In the UK today, **only trucks** compatible with LNG have been deployed, both with dual fuel and dedicated ICE engines

b. LNG is dispensed at -120°C to -162°C and 2 to 11 bar from on-site cryogenic tank storage

c. LNG is distributed to refuelling stations via road delivery therefore station sites are not restricted to an existing pipeline network

d. Some LNG stations are capable of dispensing both LNG and CNG (L-CNG stations)

Compressed Natural Gas (CNG) $CH_{4(g)}$

Key characteristics

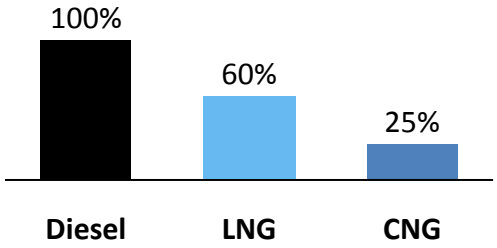
a. In the UK today, the main CNG compatible vehicles deployed are **trucks (250 bar), buses & vans (200 bar)** both with dual fuel and dedicated ICE engines

b. CNG is dispensed at ambient temperature and 200-250 bar from on-site high pressure tank storage

c. CNG is distributed via pipeline by the gas grid network, restricting station distribution to grid geography for economic and practical reasons

d. Stations are restricted to dispensing CNG only

Volumetric energy density relative to diesel:



Key technical issues:

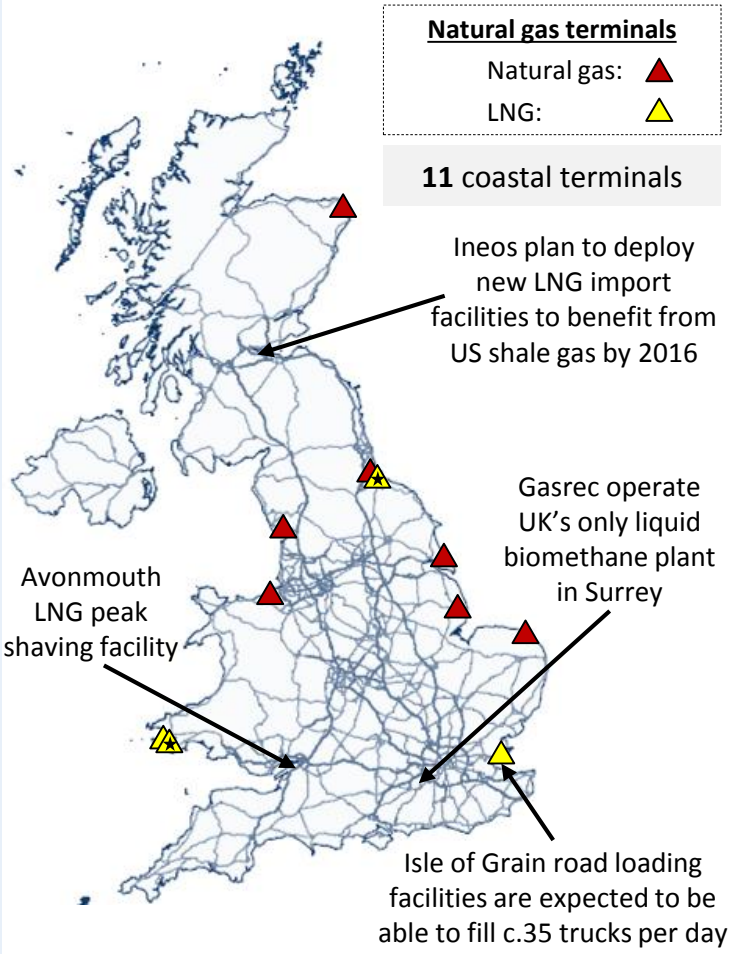
Methane slip	Incomplete combustion of all methane delivered to ICE engine resulting in methane exhaust emissions
Methane venting	Partial escape of methane into the atmosphere due to boil-off from LNG storage containers

The EU requires CNG and LNG infrastructure deployment and this roadmap aims to illustrate the requirements

Note, current policy focus and end user demand indicates that natural gas powered vans will not play a major role in decarbonising the UK transport system and are therefore not explicitly mentioned in this infrastructure roadmap

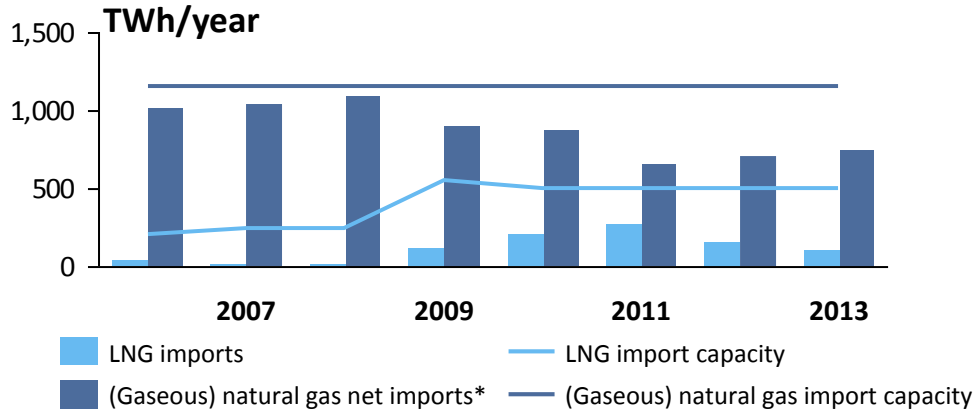
The UK currently imports two thirds of its total natural gas supply via eleven operational natural gas import terminals

Natural gas terminals



★Teeside and Dragon (Milford Haven) LNG import terminals are currently inactive

Annual UK natural gas supply



UK natural gas supply source

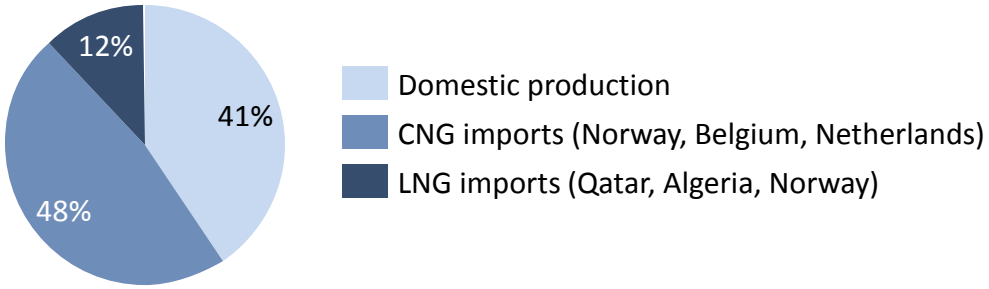
- In 2013, import capacity for natural gas / LNG was 65% / 20% utilised
- Avonmouth peak shaving plant (natural gas to LNG) is expected to end operations by 2016 due to increasing costs and reliability issues
- Isle of Grain's road loading facilities are expected to be completed by September 2015, thereby ensuring a secure supply for LNG stations for the majority of the UK
- It may be more economical to supply areas of northern UK by shipping LNG trucks from Europe to northern UK ports

SOURCE: DUKES Chapter 4 (2014), BP Statistical Energy Review (2014), Entsog European Natural Gas Network (2014), GLE LNG Investment Database (2014). *Natural gas net imports = total domestic production + total imports – total exports

Existing natural gas production and import activities are expected to continue beyond 2030

The UK has been a net natural gas importer since 2004

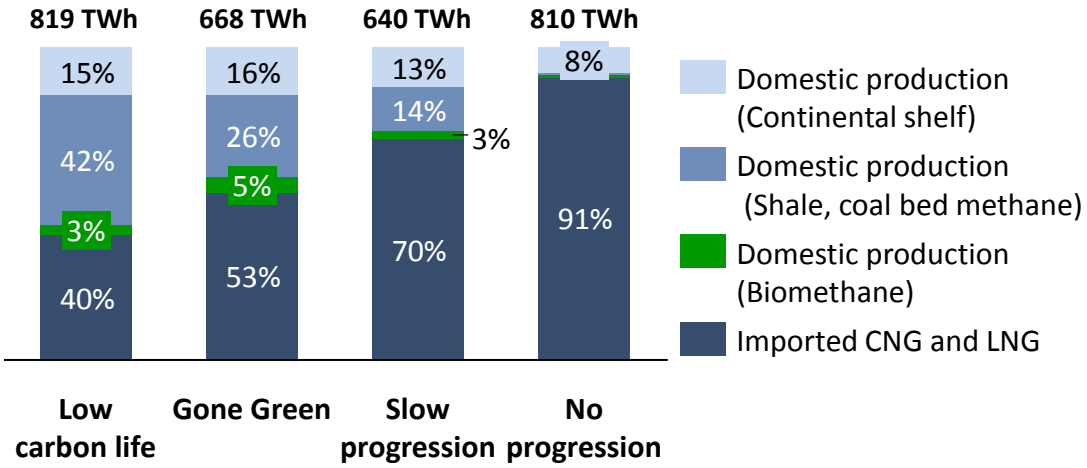
UK natural gas actual supply composition (2013)



- UK production from North Sea gas fields has declined and has been supplemented by pipeline-ready CNG from continental Europe
- A number of LNG terminals contribute to UK supply by vaporising LNG imported by tanker ship

National Grid has multiple natural gas supply scenarios

UK natural gas predicted supply composition (2035)



- Continued imports and potential domestic production of shale gas and coal bed methane will be key future sources of natural gas supply to the UK
- National Grid predicts up to c. 35 TWh of domestic biomethane production in the UK[1], **maximum 5% of total supply**
- Existing natural gas supply strategy is expected to support UK demand beyond 2050

SOURCE: National Grid "UK Future Energy Scenarios" (2014)

1 – This is the 'Gone Green' case. Under current incentive the 'No progression' case is most likely in terms of biomethane production in the UK

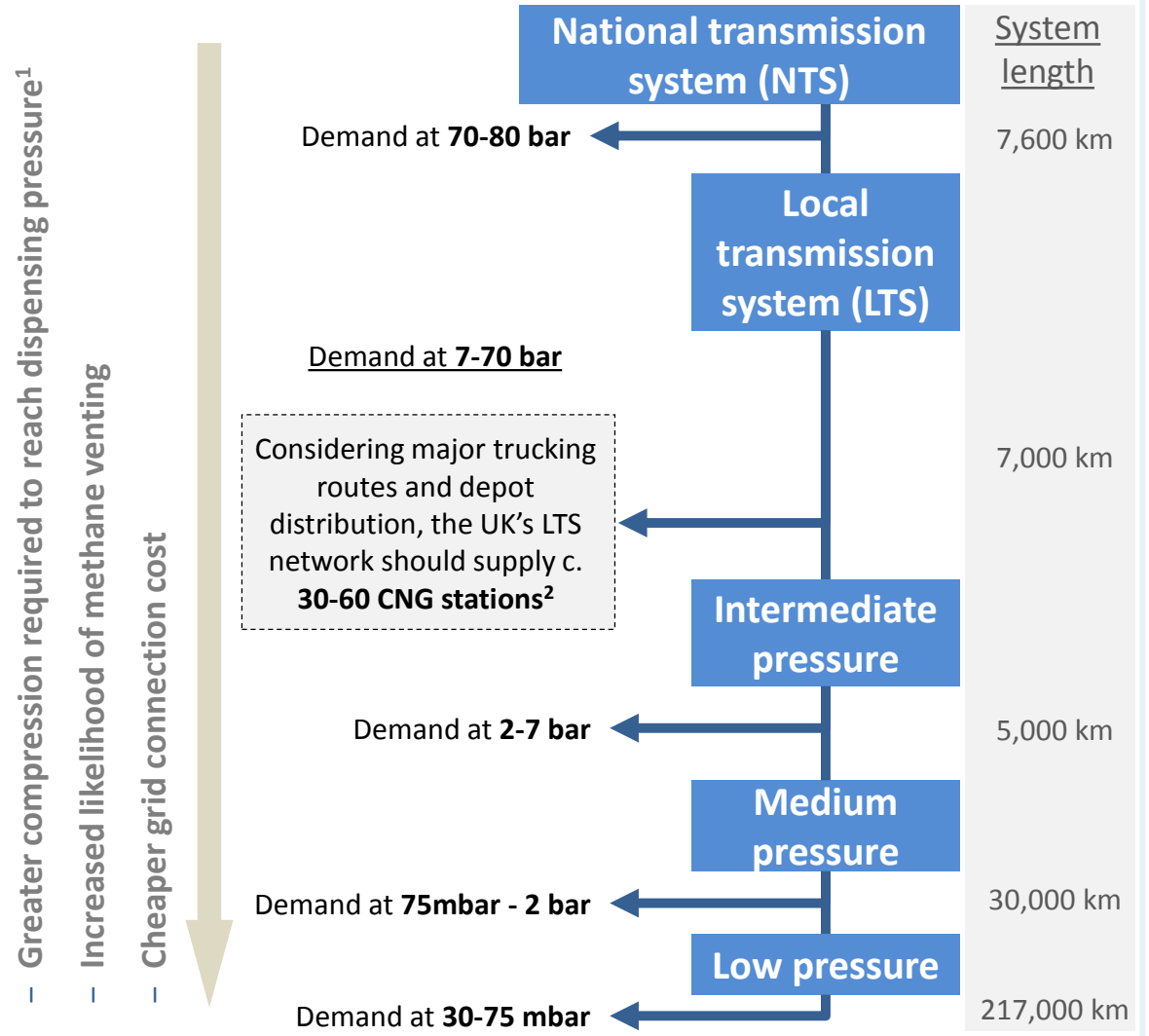
The majority of the gaseous natural gas supply in the UK is distributed via the gas grid network consisting of varying pressure outlets

methane

CNG distribution and station siting

- The majority of CNG is delivered to customers **via pipeline** with limited truck based deliveries **eliminating the need for end users to bunker fuel** at private depots
- The **Local Transmission System** (LTS) provides the **best economic solution to access gas** for transport applications, therefore public CNG forecourt siting should consider LTS connection whenever possible
- If LTS access (see next slide for map) is not available, Intermediate or Medium pressure networks should be considered for existing commercial depots
- Northern Ireland's gas grid infrastructure is significantly less mature than Great Britain

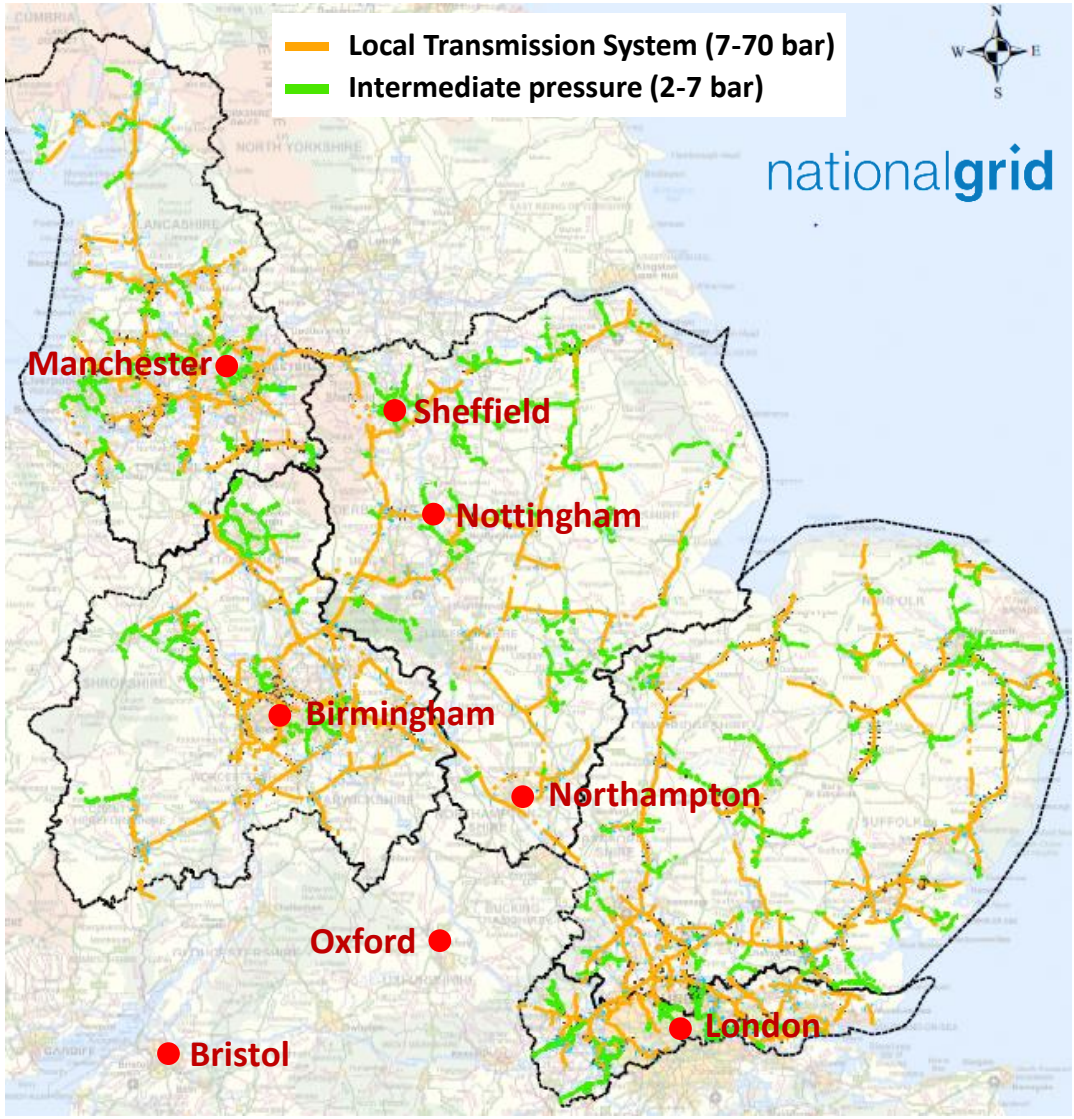
Gas distribution network – most extensive high pressure system



1- Cost advantage depends on length of pipeline between network and filling station, c. £200-500k per km

2 - Based on work done by CNG Services for National Grid)

CNG station siting should balance the benefits of higher pressure grid access and geographic compatibility with the major demand



CNG station grid access

- The **Local Transmission System (LTS)** provides the **most cost effective grid access point on an opex basis** since the least compression is required for dispensing at 200-250 bar
- LTS **accessibility is varied**; pipelines pass through and interconnect major urban areas but do not consistently follow major trunk roads and motorways
- Existing depots fortunate enough to have LTS access in their proximity should exploit the benefits or consider Intermediate Pressure (IP) network connection if LTS is unavailable
- **Intermediate Pressure (IP)** access requires greater compression but capital costs for equipment and grid connection are likely to be lower (e.g. connection to LTS has higher costs (c.£200k) than connection to IP)

Source: National Grid

LNG is delivered inland by trucks; UK based truck loading is available at Avonmouth terminal and soon Isle of Grain terminal (from late 2015)

methane

LNG distribution and station siting implications

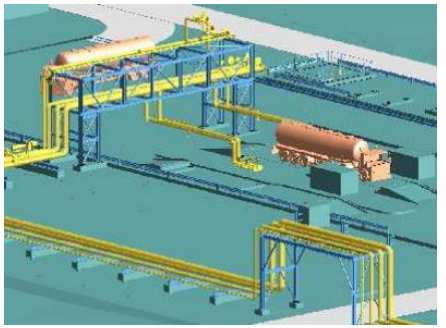
- **LNG is delivered via trucks** with cryogenic storage tanks
- In the UK, currently only one active LNG facility has road loading facilities (Exxon Mobil's Avonmouth Terminal, due to close in 2016)
- Road distribution allows **refuelling station siting to be more flexible** and does not have the geographic restrictions of pipeline delivery of gaseous natural gas
- L-CNG stations receive LNG from road truck delivery and store some LNG in cryogenic tanks as well as vaporising on-site and compressing to 200/250 bar, allowing both liquid or gaseous fuel to be dispensed

Avonmouth truck loading facilities

Evolving LNG supply in the UK

- Following a series of upgrades, in 2010 Isle of Grain became Europe's Largest LNG terminal with **1 million m^3 of static storage** and **15 million tonnes/year capacity** for gasification and injection into the gas grid
- In 2012, National Grid indicated plans to install road loading facilities with a capacity to fill **32-36 LNG tankers (40 m^3/tanker) per day,** expandable across four bays
- The new service is expected to become available late 2015

nationalgrid

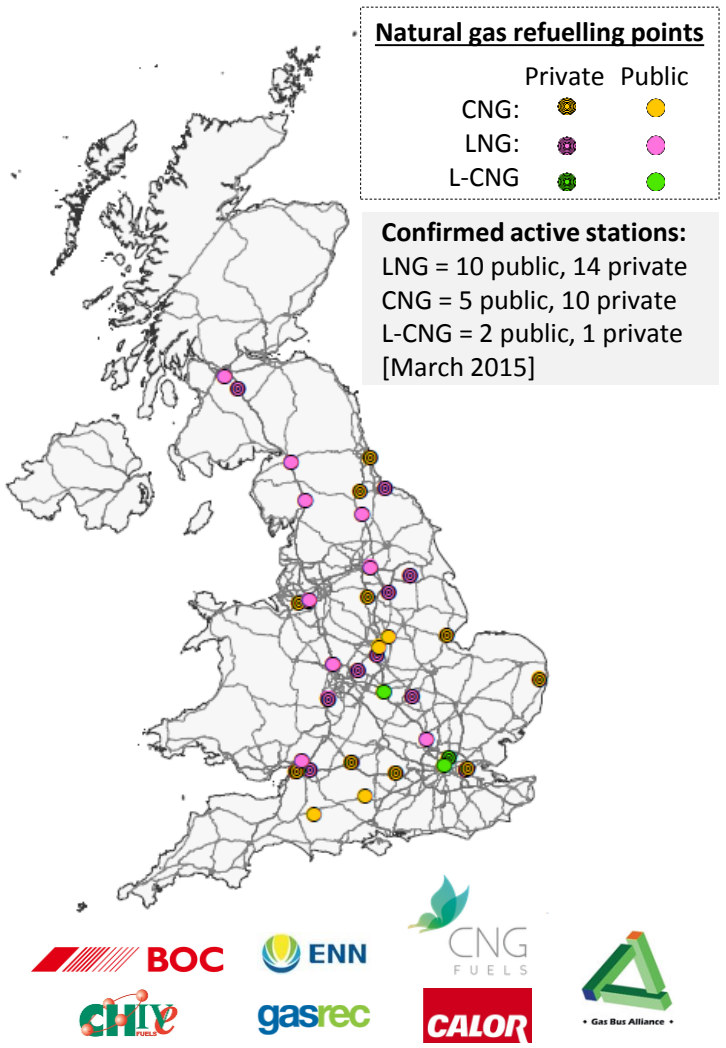


Design plan for Isle of Grain truck loading facilities

Source: National Grid

Refuelling infrastructure technology is mature but public coverage in the UK is low, the majority being located at dedicated private depots

Natural gas refuelling geography



UK refuelling network – existing infrastructure

- Disclaimer: Up-to-date information detailing active natural gas stations was not readily available at the time of writing and a number of inaccuracies were identified in public databases
- Based on industry consultation, existing infrastructure includes 25 private depot stations, with c.60% offering LNG and 17 public forecourts with a similar LNG/CNG mix
- A further 7 refuelling stations (mainly LNG) have received grant funding through the UK's Low Carbon Truck trial and are due to be built over the next 2-3 years (note, funding availability ends in 2015)

UK refuelling network – innovative solutions

- A number of fleet operators have deployed **semi-private refuelling facilities** under **cooperative contractual arrangements** allowing pre-agreed operators to share each others facilities
- Advantages of this approach include **maximising station throughput** and **reducing dependency on public infrastructure rollout**

Sources: Gasrec, ENN, Calor, Gas Bus Alliance, BOC, Low Carbon Truck Trial, Element Energy

Trials of gas HGVs are currently being supported by the UK government to monitor performance and inform its gas-for-freight strategy

methane

LCT trial will engage commercial vehicle operators

- **13 projects** for Low Emission Trucks selected for OLEV-TSB funding in 2012, total funding of **£11.3 million**
- **354 trucks** (all gas except for 10 Used Cooking Oil dual fuel tractors) to be trialled from 2013/14 to December 2015, almost doubling the current UK stock

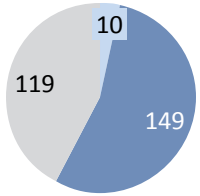
Funding will significantly improve the UK infrastructure

- **17 new gas stations** will be opened (mostly LCNG) and **8 existing stations will be upgraded** (methane vent capture)
- By September 2014, 10 (new or upgraded) stations had been made available through the trial – the remainder are awaiting planning consent
- As of Oct 2014, LNG and CNG dual fuel trucks make up c.50% and c. 40% respectively of vehicles deployed under the trial
- Truck performance is being monitored with an operational target of 15% TTW CO_2 relative to incumbent diesel vehicles
- Results from trial will **provide the evidence for future government plans** for gas freight support
- The trial should also **advance station knowledge** e.g. planning/design length, barriers to rollout, performance

Technology Strategy Board
Driving Innovation

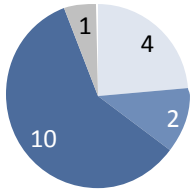
Office for Low Emission Vehicles

Vehicle deployment (as of Oct 2014)



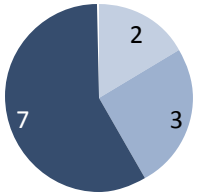
LCT trial status: 278 in operation, further 76 to be deployed

Station deployment (planned)



LCT trial status: 10 in operation, further 7 to be completed

Truck users in trial



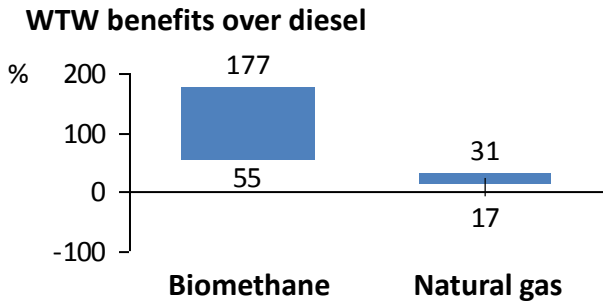
Sources: DfT presentation at NGV day June 2014, Low Carbon Truck and Refuelling Infrastructure Demonstration Trial Evaluation (Sept 2014), direct communication with Atkins TTW = Tank to Wheel

Analysis quantifying CO_2 emissions associated with natural gas used for transport is inconsistent and contains many uncertainties

methane

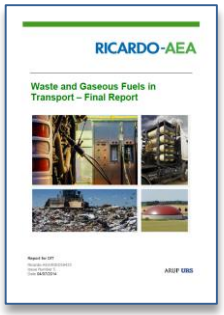
WTT = Well to Tank
TTW = Tank to Wheel
WTW = Well to Wheel

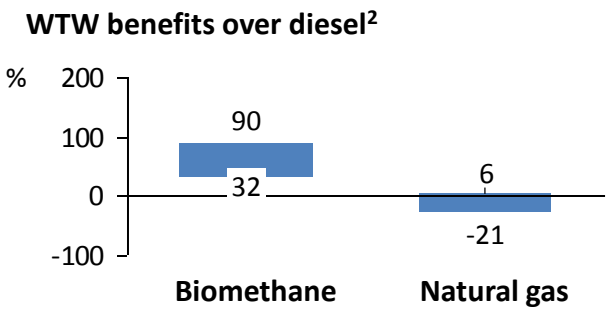
Joint Research Council report for EC (2014)



- Analysis calculates WTW benefits combining WTT analysis with a constant TTW value[1] for all natural gas scenarios
- This well-recognised study **compares only six different natural gas and biomethane scenarios** and has **no consideration of variable powertrain impacts**
- Furthermore, the study is not UK specific

Independent report for DfT (2014)





- Impacts from LNG storage **boil-off, vehicle efficiency and methane slippage** were not accurately assessed due to unavailable or incomplete data
- As such, the authors concluded the report to contain considerable uncertainty

Existing analysis identified optimal CNG and LNG siting considerations but contains high uncertainty

- Key findings: CNG WTT emissions increase when connected to **lower pressure grid points** (leaks) and LNG WTT emissions increase with **greater distance between LNG terminal and station**
- Both studies identified significant CO_2 savings from the use of biomethane as an alternative to natural gas
- The ETI has commissioned an extensive modelling exercise[3] to **improve understanding of GHG emissions associated with all key stages of WTW natural gas pathways specific to UK**

[1]60 gCO_2/MJ_{fuel}, [2]Ranges for small HGVs, large HGVs and buses, [3] Public RfP "Gas Energy System Well to Motion Modelling for Heavy Duty Vehicles". Source: JRC (2014), Ricardo-AEA (2014)

Standards and regulations for CNG and LNG provide certainty over safe siting practices but local interpretation can cause delays

The **Institution for Gas Engineers and Managers** (IGEM) provide technical standards for the UK and global natural gas supply chains

The **Health and Safety Executive** (HSE) aims to "secure the health, safety and welfare of people at work… by applying a mix of intervention techniques including inspection, advice and support"

The **British Compressed Gases Association** (BCGA) aims to "promote and advise on safe practice, participate in standards making, and assist in the preparation of practicable legislation"

Standards and codes of practice

- Many **existing standards have been developed**: IGEM/UP/5 (standard for CNG), COMAH regulations for LNG, IGEM/UP/20 (to become the new UK technical standard for CNG fuelling stations covering piped natural gas from the supply network and piped bio-methane supply)
- A number of **future standards are also being developed**: IGEM/UP/21 (available late 2015) will become guidance document for LNG refuelling stations, complementing ISO/DIS 16924 and BCGA code of standards
- Standards in place aim to **eliminate uncertainty surrounding the safe siting of CNG and LNG stations**
- However, **installation delays are common**, slowed down by inconsistent interpretation of standards by LAs
- Industry feels it is HSE's responsibility to develop **planning permission guidelines** by combining existing standards and regulations with industry input

SOURCE: Element Energy, CNG Services, www.igem.co.uk

COMAH: Control of Major Accident Hazard

In 2014, the European Commission issued a directive to help harmonise technical specifications for methane infrastructure for transport

- The **Clean Power for Transport** program, initiated in 2013, aims to facilitate the development of a single market for alternative fuels for transport in Europe
- The resulting **2014/94/EU directive** on 'the deployment of alternative fuels infrastructure' aims to:
  1) Harmonise technical specifications for recharging and refuelling stations
  2) Develop clear, transparent fuel price comparison methodologies
  3) Ensure Member States develop national policy frameworks to support the deployment of alternative fuel technologies and infrastructure

Natural gas supply for transport

- CNG and LNG connectors and receptacles for vehicle refuelling
- LNG, CNG and L-CNG refuelling points for motor vehicles
- LNG, CNG and L-CNG refuelling station geographic distribution

UN ECE Regulation 110 ISO/DIS 12617

UN ECE Regulations: ISO/DIS 16923, ISO/DIS 16924

- LNG stations for heavy duty motor vehicles along the TEN-T core network should be **approximately 400 km** apart
- CNG stations in urban and sub-urban areas along the TEN-T core network (at least) should be **approximately 150 km** apart

TEN-T Core Network

SOURCE: European Commission Press Release Database

TEN-T: Trans-European Transport Networks

CNG stations in the UK dispense at 200 and 250 bar for buses and trucks respectively whereas CNG stations in the EU dispense at 200 bar only

methane

CNG refuelling infrastructure in the EU

- Two common standards are relevant to the design of vehicle tanks:
  1. ISO 11439 stipulates a working pressure of **200 bar but permits other working pressures** (including 250 bar)
  2. UN ECE-R110 stipulates a working pressure of **200 bar only**
- OEMs are focussed on the UN standard and therefore are only interested in developing 200 bar vehicles
- This is reflected by the deployment of (mostly) 200 bar CNG refuelling infrastructure in mainland Europe

CNG refuelling infrastructure specific to the UK

- Two types of CNG dispenser nozzle commonly exist:
  1. 200 bar nozzles are designed to refuel vehicles in accordance with refuelling standard ISO 14469-1
  2. 250 bar nozzles are designed to refuel all ISO 14469-1 non-compliant CNG vehicles
- All gas buses and vans in the UK currently have 200 bar tanks whilst retrofitted gas HGVs tend to have 250 bar tanks
- Importantly, the **two nozzles types are not cross-compatible**

Implications for future CNG infrastructure in the UK

- CNG station standard ISO/DIS 16923 is unlikely to stipulate a single dispensing pressure
- Multiple dispensing pressures are unlikely to negatively impact OEMs decisions to bring HGVs to the UK market

SOURCE: European Commission, industry input

Contents

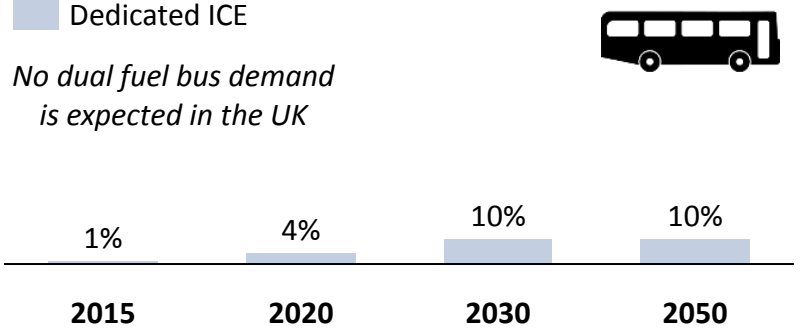
Natural gas vehicle uptake has been projected, in line with policy drivers, to quantify the methane demand in road transport

In consultation with the LowCVP Fuels Working Group, we derived uptake scenarios for new powertrains/fuels, they are policy led, typically based on CCC targets. Scenarios are used to forecast infrastructure required to match transport policy ambition and estimate the corresponding upfront costs of this infrastructure

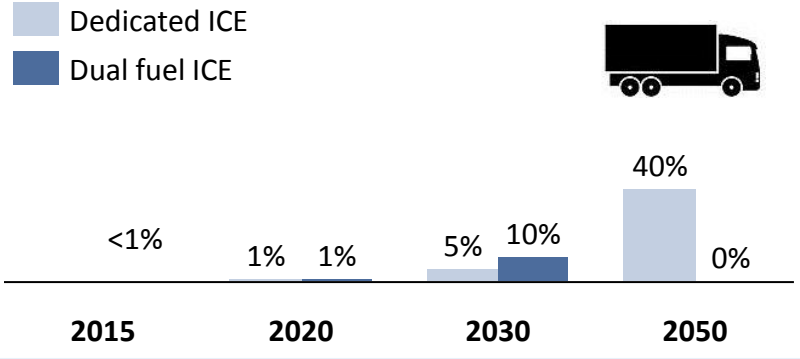
In the case of natural gas vehicles, uptake is exclusively in the heavier vehicle segments

- A **single uptake scenario** was developed for HGVs and buses –see "Introduction and background"
- Uptake of natural gas ICE passenger cars and vans is not expected to play a significant part in the UK's road transport decarbonisation activities
- **Buses** are expected to use **exclusively CNG** with **only dedicated natural gas engines** (no dual fuel)
- **HGVs** will use **both CNG and LNG** depending on vehicle operation (e.g. long haul versus inner-city) and will use **both dual fuel (diesel and methane) and dedicated engines** up to 2030 and by 2050 all vehicles will be dedicated fuel
- We refer to 'CNG' and 'LNG' but the methane could be biomethane – the molecule being the same, there is no difference in terms of infrastructure considerations

Market share of natural gas buses (new sales)



Market share of natural gas HGVs (new sales)



Source: uptake scenarios presented in Appendix

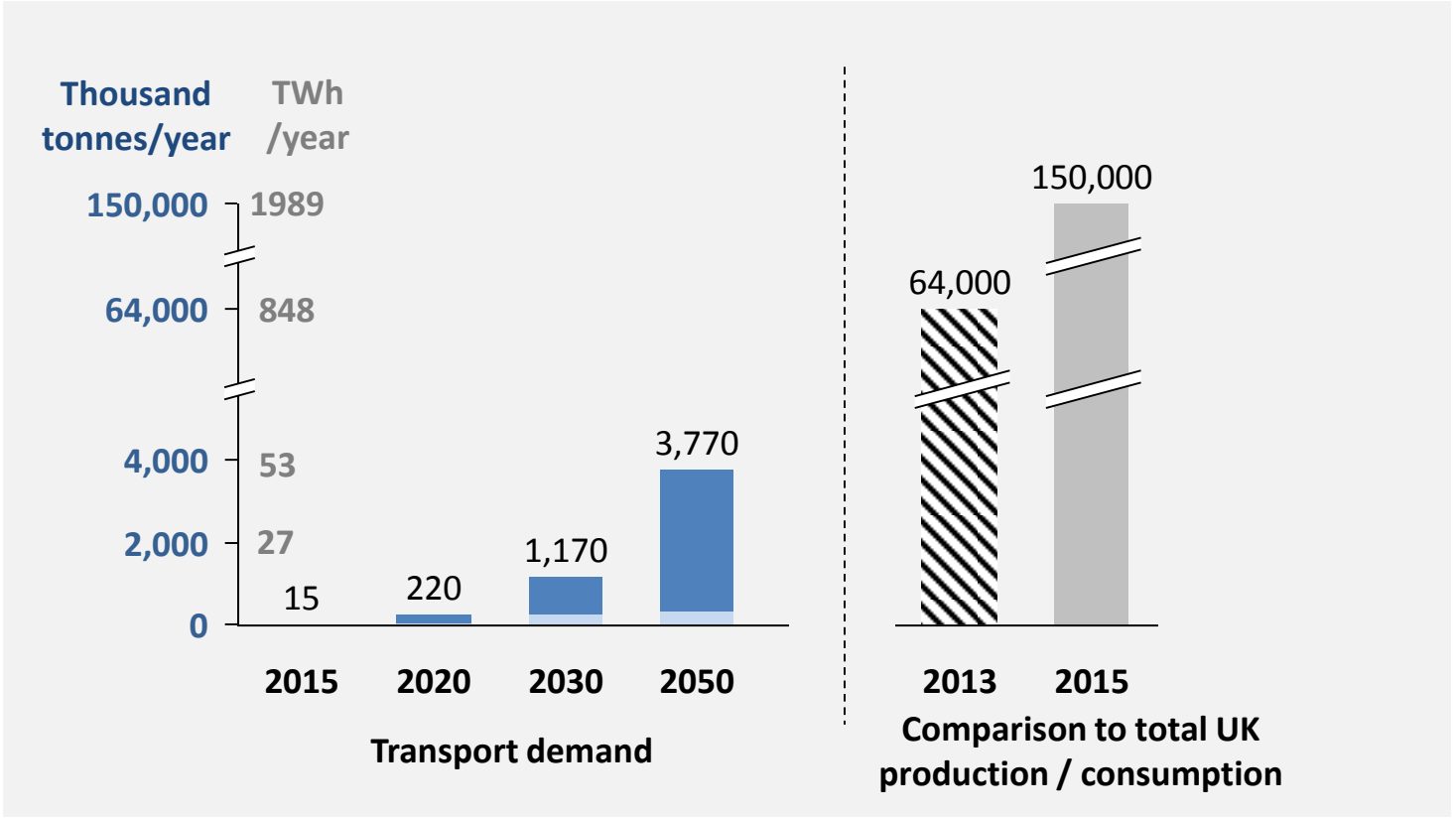
Three separate classes of HGV (varying in size) are considered in the roadmap with a single bus class to make up total HDV demand

methane

			
Weight	**3.5-7.5 tonnes**	**7.5-18 tonnes**	**>18 tonnes**
Description	Smaller 2-axle truck, rigid	Larger 2-axle truck, rigid (mostly)	Multi axle truck, articulated
Application	Local construction / commercial delivery	Refuse collection, intercity delivery	Long-haul deliveries
Mileage	30-60,000 km/year	30-60,000 km/year	>60,000 km/year
Share of stock (UK HGV fleet, c. 469k)	12%	46%	42%
Diesel consumption	22 L/100km	27 L/100km	36 L/100km
Natural gas consumption	n/a	15-20 kg/100km	20-30 kg/100km
Natural gas vehicle type	Not applicable	Dedicated and dual fuel (60% gas, 40% diesel) both LNG and CNG by 2030, dedicated only by 2050	Dual fuel LNG only

SOURCE: DfT "Guide to lorry types and weights" (2013), DfT "Vehicle Licensing Statistics" (2014), DfT "Fuel consumption by HGV vehicle type in GB, 1993-2010", DECC "Energy Consumption in the UK" (2014)

Total expected natural gas demand for transport by 2050 represents c.6% of the UK's total natural gas consumption in 2015



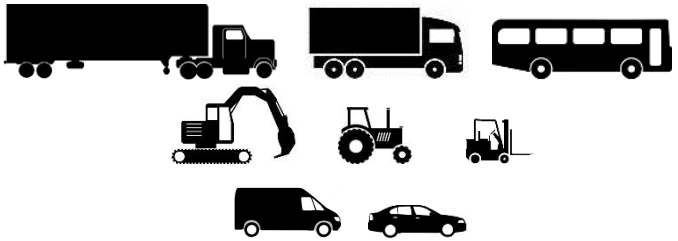
Source: Element Energy analysis (2015), DUKES Chapter 3 (2014)

Based on current refuelling patterns for heavy duty vehicles, gas trucks and buses will require both depot stations and public stations

There are broadly two types of refuelling infrastructure for liquid fuels in the UK:

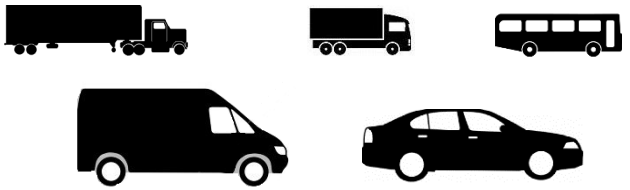
Refuelling at private depots: c.40% diesel sales

- Large fleet operators including public transport operators, hauliers, logistics companies, forklift operators tend to operate designated refuelling depots suited to their 'return to base' operations
- Such facilities tend to be private and exclusively service a single vehicle type
- **Most buses and heavy good vehicles refuel in depots** – share of diesel supplied through depot:
  - 90% for buses, 40% for coaches
  - 80% articulated trucks, 45% rigid trucks



Refuelling at public forecourts: c.60% diesel sales

- Generally, public vehicle refuelling (passenger cars, vans, motorbikes, scooters) is facilitated by one of the UK's c.8,600 forecourts
- Refuelling forecourts are publically accessible and are generally owned and operated by large oil companies (e.g. Shell, BP, Esso, etc.), independent retailers and supermarket chains



Source: Element Energy, DfT Modes 3 study (2011)

Dedicated gas buses will require mainly depot-based stations and high uptake projections suggests c.210 stations could be needed by 2050

methane

	2020	2030	2050
Vehicle stock: (no. of buses)	**c.2,000**	**c.10,000**	**c.17,000**
Energy demand: (tonnes/year)	**c.50,000**	**c.220,000**	**c.340,000**
Required stations:	**c.80** (2t/day, 80% utilisation)	**c.130** (5t/day, 90% utilisation)	**c.200** (5t/day, 90% utilisation)

Short/medium term

- Vehicle fleets of c.15-30 CNG buses requiring c. 100kg/day/bus stations
- Intra and inter-city bus operation generally adopt return to base refuelling, therefore dedicated CNG stations will be deployed at private depots
- Smaller fleets (<15 buses) will be more suited to L-CNG stations, to avoid grid connection costs
- Increasing number of suppliers offering turn-key solutions including infrastructure, vehicles and fuel supply (e.g. Gas Bus Alliance)
- As accreditation for low emission bus grants begin to consider full WTW pathways, biomethane supply is likely to increase accordingly

Long term

- Key learnings from trials (e.g. 20 CNG buses in Reading) will improve station design
- Increased fleet sizes (50 buses) requiring larger 5t/day stations, will be clustered around optimal gas grid access points to improve business case
- Large feasibility trials (e.g. 200 bus deployments)
- Greater interest from UK's 'Big 5' operators[1] with strong environmental drivers
- All gas buses run on CNG today but a transition to LNG is technically possible (e.g. Scania have developed a dedicated LNG bus); refuelling infrastructure will need to adapt to vehicle developments

Infrastructure investment must be flexible with respect to uptake of other low carbon transport fuels

[1]Stagecoach, Arriva, First, Go Ahead Group and National Express make up 67% of market share for UK bus services

Fleets of dedicated and dual fuel gas HGVs will require c. 35% of fuel demand from public forecourts with the remainder from depots

methane

	2020	2030	2050
Vehicle stock: (no. of HGVs)	**c.8,000**	**c.50,000**	**c.190,000**
Energy demand: (tonnes/year)	**c.200,000**	**c.1,000,000**	**c.4,000,000**
Required 10t/day stations:	**c.45** (15t/day stations, 90% utilisation)	**c.230** (15t/day stations, 90% utilisation)	**c.800** (15t/day stations, 90% utilisation)

Short/medium term

- OEM vehicles increasingly available to the UK market
- We expect **LTS and IP connectivity for CNG stations** to be a main focus given WTW and economic benefits
- Key learnings from OLEV Low Carbon Truck trial are disseminated and **inform future station design**
- Ensure public natural gas refuelling network develops,[1] especially along TEN-T corridor if EU funding is sought[2] and along arterial motorways (long-haul HGVs)
- Assuming large station rollout (10t/day), c. 35 CNG and 45 LNG stations will be required in 2020[3]

Long term

- Increased public infrastructure will allow small fleet HGV operators to deploy NG vehicles and enable large fleet operators to increase payload and cover longer distances
- Unclear whether infrastructure rollout will continue deployment along TEN-T Core Network or develop cluster networks of refuelling infrastructure around key cities

Infrastructure investment must be flexible with respect to uptake of other low carbon transport fuels

[1]>75% of HGVs are in small fleets of <6 vehicles (DfT, 2011). [2]In 2015, existing publically accessible CNG station network adheres to EU directive requirements south of Crewe / Nottingham. [3]Assuming same market share as today.

Long distance trucks (and intercity coaches) will require further development of the public refuelling infrastructure

methane

Existing infrastructure

Questions to industry

- Is the 400km separation distance between LNG stations sufficient, as stipulated by the EU directive?
- Is the 150km separation distance between CNG stations suitable?
- Is the EU Directive a suitable policy for directing infrastructure rollout?

Note, all motorways and 'trunk' A roads in the UK have a total length of 12,000 km,[1] suggesting a need for only 80 CNG stations and 30 LNG stations

Feedback from industry

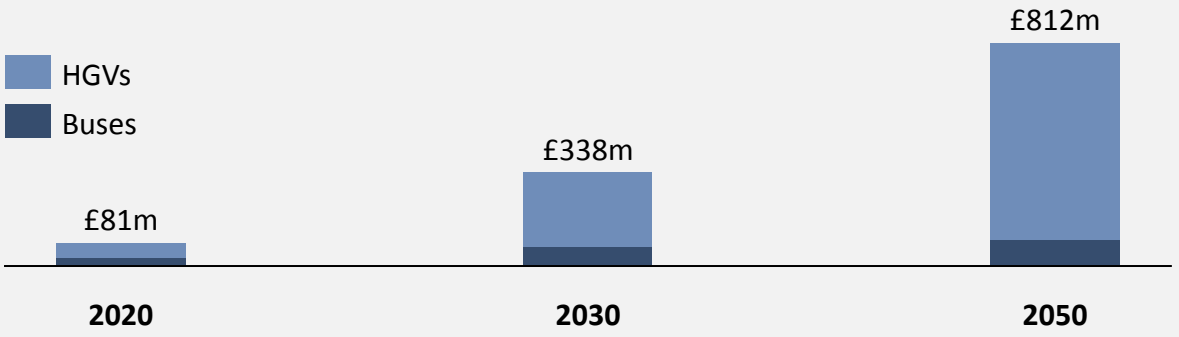
- In 2015, the majority of existing facilities are located at private depots
- Short term public refuelling infrastructure rollout will be focused around demand, not necessarily in accordance with the TEN-T corridor
- Cooperative models allowing semi-private facilities to be shared will be considered in the early years to maximise throughput
- Infrastructure build-up is expected to be focused around the 'golden triangle' between Bristol, Manchester and London, with supporting infrastructure at necessary outlier locations
- Furthermore, a network of equally spaced refuelling sites is unlikely to develop

[1]DfT "Road lengths in Great Britain" (2013)

Approximately £0.8 billion is required to deploy sufficient infrastructure to support increasing numbers of natural gas vehicles in the UK

	2020	2030	2050
Vehicle stock: (no. of buses)	c.2,000	c.10,000	c.17,000
Energy demand: (tonnes/year)	c.50,000	c.220,000	c.340,000
Required stations:	**c.80** (2t/day, 80% utilisation)	**c.130** (5t/day, 90% utilisation)	**c.200** (5t/day, 90% utilisation)
Vehicle stock: (no. of HGVs)	c.8,000	c.50,000	c.190,000
Energy demand: (tonnes/year)	c.200,000	c.1,000,000	c.4,000,000
Required 10t/day stations:	**c.45** (15t/day, 90% utilisation)	**c.230** (15t/day, 90% utilisation)	**c.800** (15t/day, 90% utilisation)

Approximate level of infrastructure investment required (station capital & civils costs only)



Grid capacity has not been considered when producing overall station numbers. It is important to recognise that whilst overall spare gas grid capacity is expected to increase, local grid constraints might emerge

Based on today's costs. See Appendix for cost assumptions

The natural gas sector will need to address several barriers to allow the transition from demonstration activities to a commercial rollout

Barrier	Description	Example solution
Gas grid accessibility	CNG stations require connection to the gas grid, often costs can be prohibitive and require lengthy approval procedures	Grid operators offer fast track applications for LTS connection
Gas grid connection services	Grid connection costs vary significantly; LTS connection is approx. £200k more costly than for IP	Operators to offer competitive LTS connection services to improve capital costs of CNG stations
Planning consent for new refuelling stations	Time to receive planning permission from Local Authorities has caused significant delays to station deployment	Pursue amendment of National Planning Policy Framework (NPPF) to give recognition of stations – *already underway.* Issue national planning guidance to facilitate planning decisions at local level
On-site natural gas storage consent	Hazardous Area Consent (15 tonne limit) and COMAH (20 tonne limit) make LNG fuel bunkering difficult	National guidelines need to be developed to allow consent for larger storage capacity for natural gas
Risk of methane venting	Liquefied methane has a high vapour pressure; methane has higher GHG effects than carbon dioxide in the short term	Optimise dispenser and storage technology to minimise venting – *already underway*
Limited access to biomethane feedstock	<10% total food waste is used for AD due to a lack of separate waste collection	Engage with Government on waste policy to accelerate introduction of separate food waste collection, increasing AD feedstock supply – *refer to DfT Transport Energy Taskforce outputs for further analysis of biomethane UK potential supply*

AD = Anaerobic digestion

The natural gas sector will need to address several barriers to allow the transition from demonstration activities to a commercial rollout

methane

Barrier	Description	Example solution
Dispenser incompatibility	Multiple dispenser nozzle types exist and their implementation has not been coordinated (e.g. LNG stations in the UK use multiple nozzle types including JC Carter, Parker Kodiak, Macrotech) resulting in drivers arriving at stations not compatible with their vehicle receptacles	Ensure all new nozzles adhere to a UK standard for both LNG and CNG (e.g. NGV2) dispensers
Gas transportation through tunnels	Road tunnels in the UK (e.g. Mersey, Dartford, Blackwell) have different restrictions for the transportation of gases	Strategic deployment of new LNG import terminals to avoid tunnels connected to major road networks

Contents

Regulatory barriers will be the primary focus for enabling natural gas infrastructure, whilst a number of technical issues must also be resolved

Infrastructure roadmap

Network characteristics (relevant to both public and private infrastructure)

Legend

Cost

Stations

Technical

	2015	2020	2025	2030	2050
Total stations	<50	c.130		c.370	800-1,000
Total cost	Financial support mainly towards fleet operators	c.£68m		c.£340m	c.£1bn
CNG	Prioritise higher pressure grid connection (2-70 bar, Local Transmission System and Intermediate Pressure) where possible. L-CNG station deployment where LNG logistics are more accessible than grid connection				
LNG	Optimise logistics for delivery of LNG to stations, improving overall WTW emissions		Strategic deployment of new LNG import terminals to minimise delivery distance to LNG refuelling stations		
Location	Commercial deployment along key trucking routes Targeted support for lower throughput regions			Wider national network expansion expected to be fully commercial	
	EU Directive guidance met: CNG and LNG stations on TEN-T Core Network, <150km and <400km inter-station distance respectively				
Access	Continued development of cooperative semi-public infrastructure shared between fleets		Greater fleet uptake provides sufficient investment confidence for large public stations deployment		
	Communicate real-time station availability and fuel price data to end users				
Station capacity	Station size range: 2, 5, 10, 15 tonnes/day	*Multiple safety standards may limit LNG storage to 15-20t*	Larger LNG and CNG stations	**LNG safety regulations modified** **Multi compressors stations for CNG**	

Natural gas vehicle stock

Thousand vehicles

Projections are based on policy-led uptake scenarios presented on page 25

Data supported quantification of infrastructure requirements

	2020	2025	2030	2050
HGVs <18t	4.0	13	26	105
HGVs >18t	4.0	12	24	85
Buses	2.0	5.1	9.7	17

Dashed lines represent high uncertainty

Major milestone /enabler

Indicative fuel economy: dual fuel HGV = 60 kg/day, dedicated HGV = 75 kg/day

Costs based industry input, future cost reductions not included

Planning guidance for Local Authorities will help speed up station deployments with key outstanding safety issues addressed

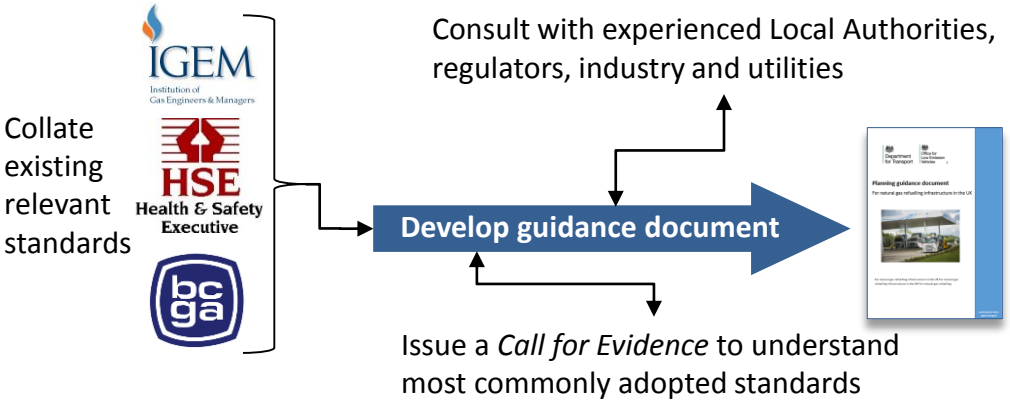
methane

1 Planning guidance

- A number of well informed, robust standards have been developed to address technical issues associated the installation of natural gas refuelling stations
- Infrastructure operators have identified inconsistent interpretation of these standards by Local Authorities to significantly delay station installation

Recommendations

Central Government: develop planning guidance document to facilitate the uniform implementation of infrastructure equipment standards



2 Safety issues

- Health and safety regulations and codes of practice only partially address infrastructure requirements

- For example, natural gas infrastructure operators have identified on-site storage allowances and safety distances to be incompatible with refuelling station deployment due to regulator unfamiliarity with the use of natural gas as a road fuel

Recommendations

Regulators: Re-evaluate and consider amendment of existing standards for on-site natural gas storage allowances and safety distances

Cross cutting recommendation: Central Gov., LAs and regulators: Establish regular dialogue with the NGV Network, to address planning, safety and other technical issues as well as get industry input on funding/infrastructure strategies

NGV Network = Natural Gas Vehicle Network, a platform of gas grid operators, gas and LNG suppliers, CNG/LNG station providers, gas vehicle OEMs and other related stakeholders

End user experience should be harmonised across UK network through standardisation of equipment and improved communication systems

methane

3 Station economics and support

- Industry asserted that economics for operating infrastructure in high throughput areas does not need support, as evidenced by commercial organisations offering turn-key solutions
- A minority of UK infrastructure projects have received grant funding[1]; further support should target areas of lower vehicle throughput/lower base demand
- Areas for optimisation include costs for high pressure grid connection and venting prevention technologies

Recommendations

Central Government: Focus on long term support for natural gas vehicle deployment and the associated infrastructure will follow growing demand if the correct regulatory and legislative arrangements are in place

Gas network operators: allow competition in LTS connection to reduce connection costs

R&D bodies: Reduce costs for venting prevention / methane capture technologies

4 End user experience

- Inconsistent infrastructure implementation has led to a fragmented driver experience at stations
- Vehicle tank receptacles are compatible with different nozzles types and dispensing pressures but no standard stipulates a specific requirement
- Station downtime (e.g. for maintenance) is often not communicated to drivers and fuel price variations can significantly impact fleet operations

Recommendations

Central Gov. & regulators: Work with industry to develop the most appropriate nozzle/pressure standard to meet UK fleet operator needs for CNG, LNG and L-CNG stations

Industry: Develop communication system to notify drivers of technical/economic factors for infrastructure (e.g. station type, fuel price and maintenance schedules)

1 - e.g. TEN-T funded projects and OLEV £4m fund for future station deployments

LTS: Local Transmission System (high pressure gas grid)

Innovative approaches such as semi-private stations provide a transition strategy before wider vehicle and station deployment in the 2020s-2030s

methane

5 Depot infrastructure sharing

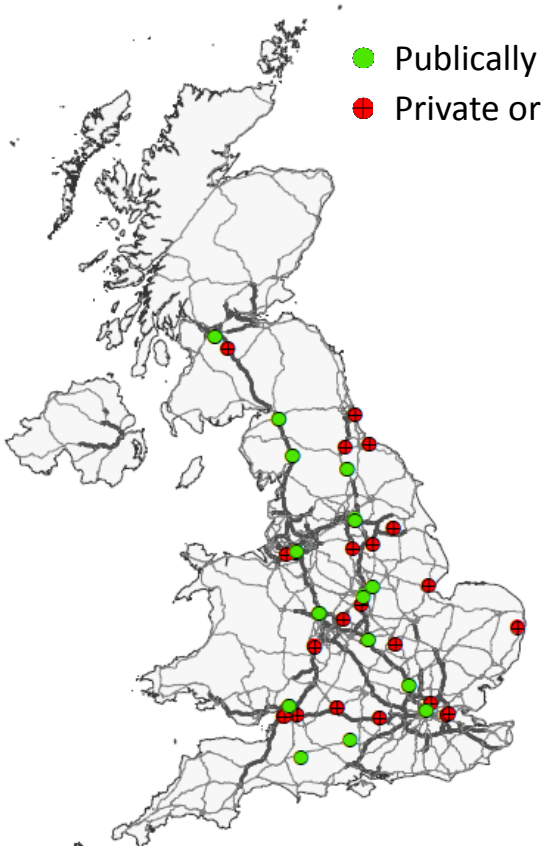
- A number of fleet operators have deployed semi-private refuelling facilities under cooperative contractual arrangements allowing pre-agreed operators to share each others facilities
- Advantages of this approach include maximising station throughput and reducing dependency on public infrastructure rollout
- Opportunities for further adoption of cooperative station ownership models will enable a transition to significant vehicle uptake when sufficient investor confidence exists for larger public infrastructure deployment

Recommendations

Central Government: consider counting semi-private stations (where facility is shared between multiple, pre-agreed users) as 'public' in the Implementation plan to be submitted to the EC as part of Directive 2014/94/EU[1]

Industry: develop commercial arrangements that facilitate further adoption of the cooperative model

Natural gas refuelling station network



Key infrastructure operators:

BOC, ENN, CNG FUELS, chiyo, gasrec, CALOR, Gas Bus Alliance

[1] Clean Power for Transport program – Directive on 'the deployment of alternative fuels infrastructure' (October 2014)

While further research is needed, measures that minimise the GHG emissions related to distribution and dispensing of gas should be adopted

6 Well-to-Tank (WTT) emissions

- In keeping with national targets for reducing transport GHG emissions, emissions relating to logistics and dispensing of gas should be minimised
- Current analysis is incomplete and UK non-specific, however some emission factors are well understood:
  - CNG station siting activities should aim to access **high pressure grid** connection points
  - LNG / L-CNG station siting activities should aim to **optimise delivery logistics** and adopt state-of-the-art **venting prevention** and capture systems
- Biomethane achieves greater WTT emission savings than natural gas but UK production is limited and incentives in place divert it to applications other than transport

Recommendations

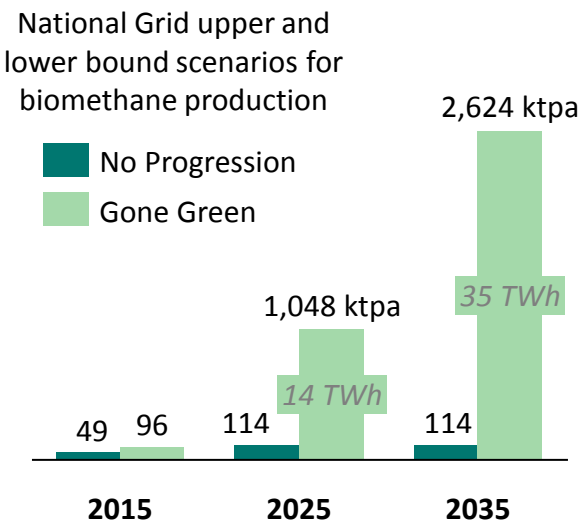
Local Authorities: Consider WTT emission factors in conjunction with planning guidance when approving natural gas station installations

Central Government: Future infrastructure strategy should consider UK specific findings (on-going ETI led analysis)

R&D bodies: Reduce costs for venting prevention / methane capture technologies

UK biomethane production potential

Graph units: ktpa (TWh shown as reference)



- National Grid has developed several scenarios of biomethane production, in the highest case it's 35TWh/year i.e. <5% of total gas demand
- Under present incentives, the 'No progression scenario' is the most likely case

Source: Element Energy

Contents

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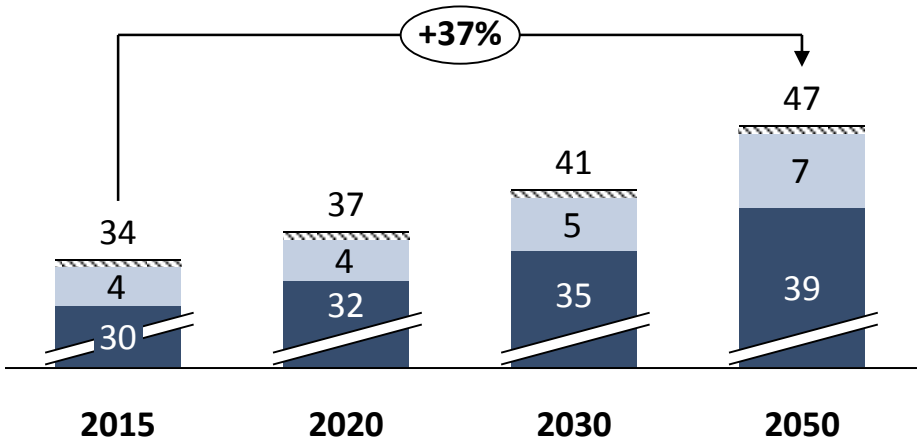
Acronyms

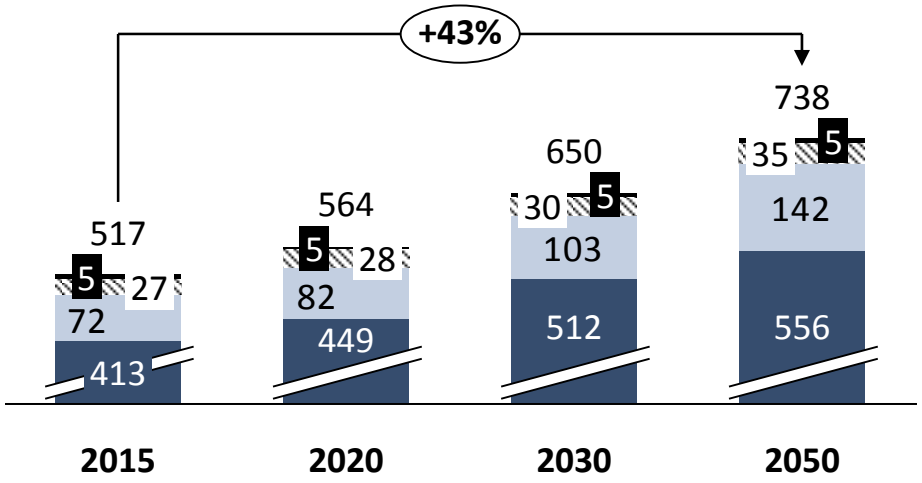
AD	Anaerobic Digestion
AFV	Alternative Fuel Vehicle
CCC	Committee on Climate Change
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
COMAH	Control of Major Accident Hazard
DECC	Department of Energy & Climate Change
DfT	Department for Transport
DNO	Distribution Network Operators
DUKES	Digest of United Kingdom Energy Statistics
EC	European Commission
EE	Element Energy
ETI	Energy Technologies Institute
EU	European Union
GBA	Gas Bus Alliance
HGV	Heavy Goods Vehicle
HSE	Health and Safety Executive
ICE	Internal Combustion Engine
IGEM	Institute for Gas Engineers and Managers
ktpa	thousands tonnes per annum
LBM	Liquid Biomethane
LCN	Low Carbon Network
LCNG	Liquefied and Compressed Natural Gas
LCT	Low Carbon Truck
LNG	Liquefied Natural Gas
LTS	Local Transmission System
Mt	Million tonnes
NG	National Grid
NG	Natural Gas
NGV	Natural Gas Vehicle
NPPF	National Planning Policy Framework
OEM	Original Equipment Manufacturer
OLEV	Office for Low Emission Vehicles
PM	Particulate Matter
R&D	Research and Development
RED	Renewable Energy Directive
TEN-T	Trans-European Transport Networks
TSB	Technology Strategy Board
TTW	Tank-to-Wheel
ULEV	Ultra-Low Emissions Vehicle
WTT	Well-to-Tank
WTW	Well-to-Wheel

The modelling of the future UK fleet is based on DfT traffic and park size projections

Total UK vehicle stock (million vehicles)



Total vehicle km travelled (billion km)



- Future vehicle projections use figures provided by DfT:
  - Cars stock to increase from c. 30 million to 39 million and c. 550 billion vehicle km travelled by 2050
  - Vans stock to increase from c. 3.5million to 7 million by 2050
  - HGVs stock to increase from c. 500 thousands today to c. 630 thousand by 2050
  - Buses stock and vehicle km travelled to stay broadly constant at around 170 thousand units and 5 billion vehicle km travelled
- Overall fleet and km increase of c. 40% between 2015 and 2050

Buses HGVs Vans Cars

Source: DfT Road transport forecasts (available online) as well as direct supply of National Travel Model outputs for the case of cars

The powertrain/fuel uptake scenarios underpinning the Infrastructure Roadmap are policy led

Uptake scenarios focus on alternative fuels

- **The scenarios used are not intended to cover all possible outcomes but instead focus on cases with ambitious uptake of alternative fuels**
- Scenarios are **policy led,** typically based on targets set by the Committee on Climate Change (sources shown next); they are illustrative rather than based on detailed of new modelling technology costs and customer decision making behaviour
- Therefore the uptake scenarios represent possible futures where low and ultra low emission powertrains are successfully deployed
- Focus is intended to provide the most interesting inputs for the analysis of the Infrastructure Roadmap – e.g. a 'business as usual' case where petrol and diesel continue to provide over 98% of road transport energy would not require new refuelling/recharging infrastructure
- In accordance with the Fuel Roadmap, blends higher than B7 are not considered for the mainstream fuels and E20 is considered only from the 2030s
- Scenarios have enabled future infrastructure requirements to be quantified and upfront costs capital costs for public infrastructure have been estimated. Cost of setting new fuel production assets, distribution/logistics costs and general infrastructure operating costs have not been considered. Costs of other incentives that might be required to achieve the uptake scenarios (e.g. vehicle grants) haven not been estimated in this study

Overview of the powertrain options considered and key sources

Cars and vans

Buses

HGVs

NRMM

RELEVANT POWERTRAINS /FUELS

- **Cars and vans**
  - ICE: petrol, diesel, LPG, (gas), (H_2 in early years)
  - EVs: Battery EVs, plug-in hybrid EVs, fuel cell (FCEVs)
- **Buses**
  - ICE: diesel, (bio)methane
  - EVs: BEV, PH/RE, FCEV
  - (Liquid air for cooling/hybrid power)
- **HGVs**
  - ICE: diesel, (bio)methane, (methanol)
  - EVs - in lighter segments only
- **NRMM**
  - ICE: diesel, LPG, (gas), Liquid air for refrigeration units
  - (Batteries and Fuel Cells – in some applications)

KEY SOURCES / INDICATORS

- **Cars and vans**
  - The Carbon Plan and the Committee on Climate Change's recommendations
  - H_2Mobility Phase 1 report, 2013
  - Historic trends for petrol/diesel split
- **Buses**
  - Current and announced commercial availability, policy drivers
  - *Alternative Powertrain for Urban buses*, 2012
  - CCC – 4th Carbon Budget Review
- **HGVs**
  - Current and announced commercial availability
  - DfT HGV Task Force
  - TSB-DfT Low Carbon Truck Trial
  - CCC – 4th Carbon Budget Review
- **NRMM**
  - *Data on fuel usage of NRMM is sparse*
  - *More qualitative approach suggested*

Parentheses indicates the powertrain/fuel option is expected to stay niche in the 2050 horizon

HGV = Heavy Goods Vehicles, NRMM = Non Road Mobile Machinery

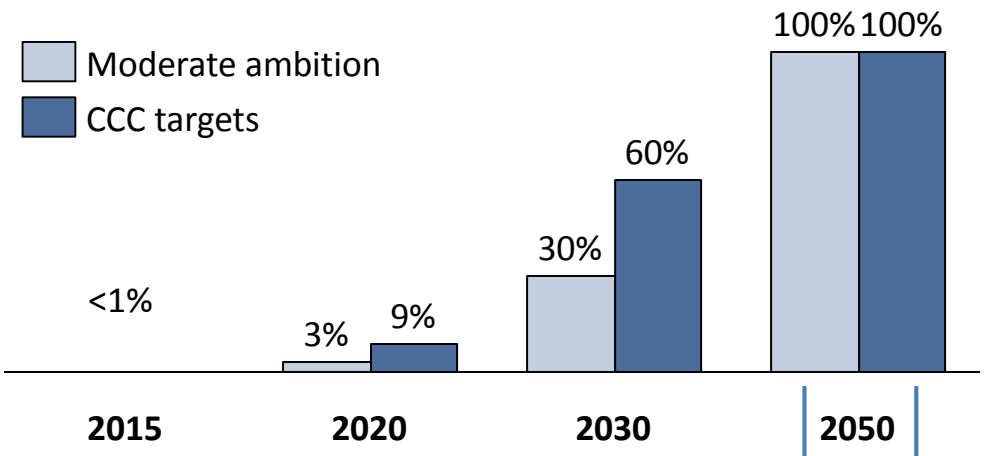
Cars and vans are expected to transition to zero emission powertrains for the UK to meet its GHG reduction targets

- Cars and light commercial vehicles ('vans') are treated together as they have the same technology options and fall under the same electrification targets in the Carbon Plan.
- Sales of vans running on **methane** are not considered in the modelling on the basis of the low commercial availability (only 2 models on the market), lack of policy drivers for growth and aforementioned electrification targets. Any gas demand resulting from vans would be small enough to be considered negligible, in comparison to the potential gas demand from trucks.
- **Dual fuel vans running on diesel and hydrogen and Range Extender Fuel Cell electric vans** (being deployed currently in the UK and in continental Europe) are not modelled explicitly. Instead, their hydrogen demand is accounted for in the 'FCEV' heading. The specific requirements for dual fuel and range-extender H_2 vans are however considered in the Infrastructure Roadmap (e.g. dispensing pressure).

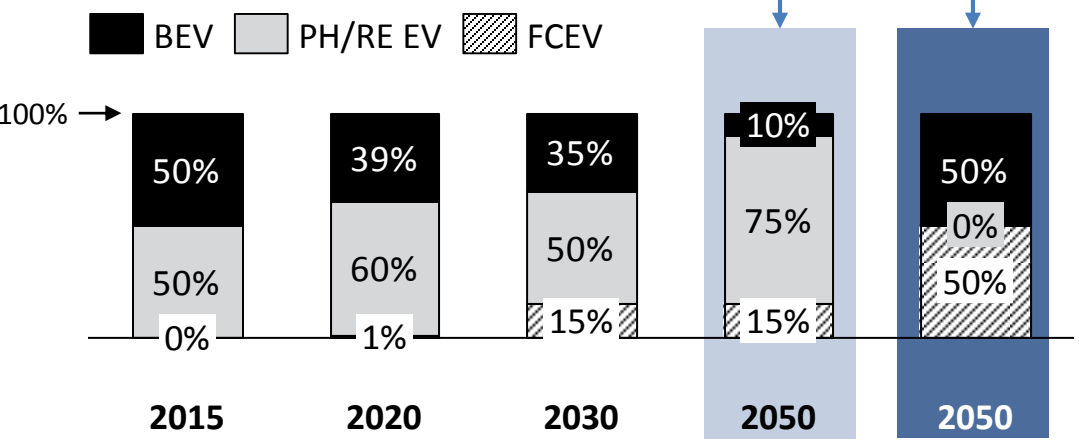
Source: Element Energy

We studied infrastructure requirements set by the Committee on Climate Change targets as well as a case with a slower EV uptake

Market share of EVs (new sales)



Breakdown of market share of EVs



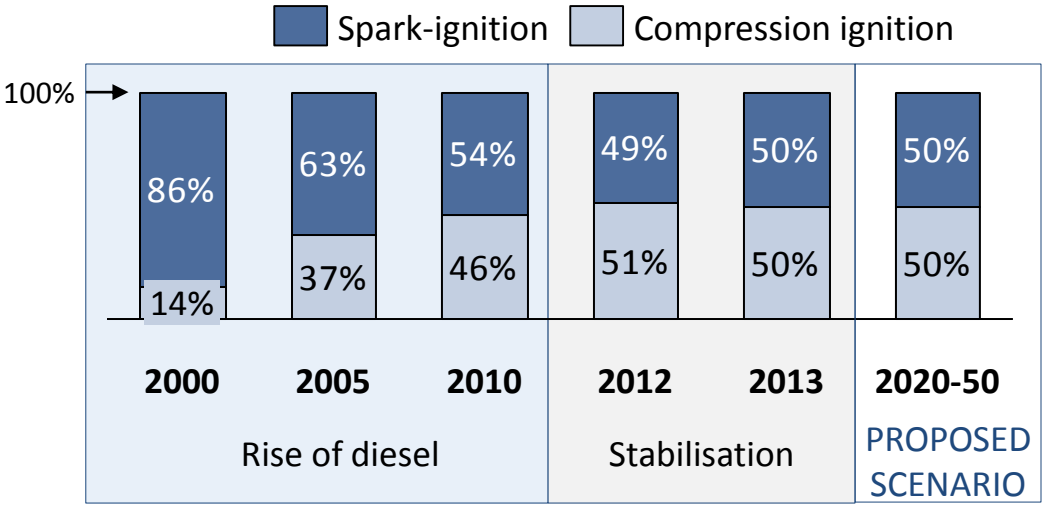
Scenarios

- Two EV uptake scenarios have been used:
  - '**CCC targets**': EVs reach 60% market share by 2030 and Zero Emission vehicles reach 100% of market share before 2050
  - '**Moderate ambition**': the 2030 CCC targets are not met but EV uptake is nonetheless high (30% new sales); by 2050 EVs represent 100% of sales but are mainly PHEVs or RE-EVs, i.e. still reliant on liquid fuels

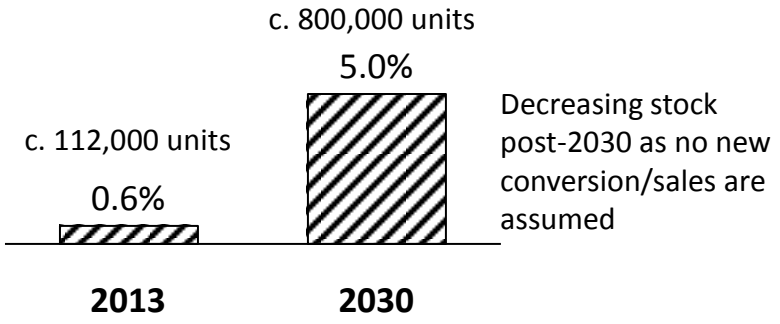
Sources: Element Energy, UK H_2Mobility report Phase 1 (2013), *Pathways to high penetration of EVs*, EE for the CCC (2013), *Options and recommendations to meet the RED transport target*, EE for LowCVP (2014)

We assumed continuation of the observed petrol /diesel share for cars and modelled an ambitious LPG uptake

Sales of new cars with Internal Combustion Engine vehicles - split between spark-ignition ('petrol' type) and compression ignition engines ('diesel' type)



Share of spark-ignition cars (ICE and HEV) stock that run on LPG



Scenarios

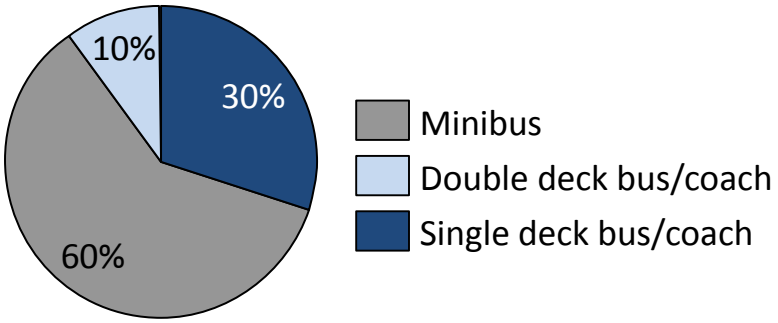
- We assumed that the current split of petrol/diesel engines for new cars (50/50) is maintained going forward
- In line with the Fuels Roadmap, diesel will be B7 (EN590) with an increasing amount of drop-in renewable diesel – i.e. no compatibility issue to be considered for the distribution infrastructure
- For petrol engines, we will evaluate the amount of:
  - Ethanol needed if the E10 becomes the main grade by 2020 and E20 by 2032
  - LPG needed for a case where the rate of conversion (or sales if OEM supply is put in place) accelerates to reach 5% of the petrol car stock (equivalent to c. 40,000 conversions per year until 2030)
- All new vans are assumed to run on diesel

Sources: Element Energy, SMMT data for 2000-2013 sales, UKLPG for LPG 2013 figures

Buses have many powertrain options but overall small fuel use so we used only one scenario, where all technologies see high sales

Current UK bus market

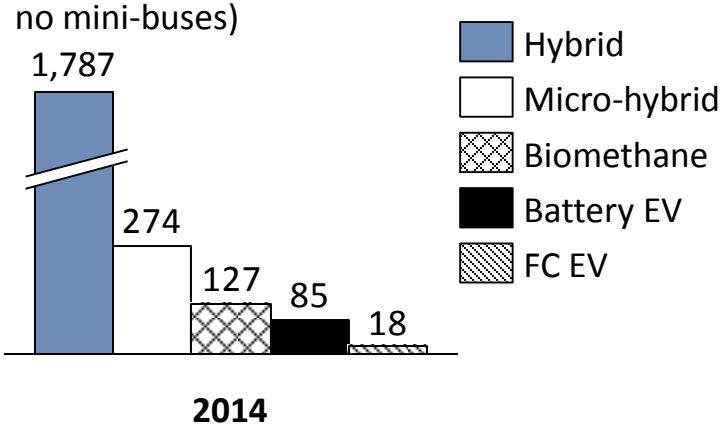
UK bus fleet, c. 165,000 vehicles:



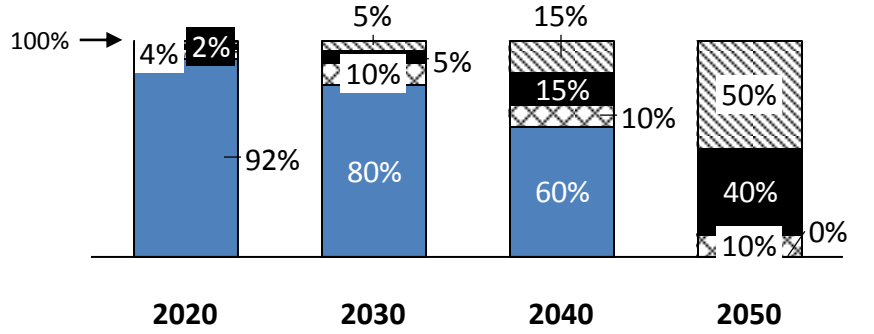
Scenario

- We ramped up the alternative fuel market share from 2030, in line with the European study[1] that suggests that the TCO of battery and FC e-city buses will become comparable and competitive with diesel and CNG buses by 2030[1]
- We assume 90% uptake for Zero Emission Vehicles by 2050
- This is lower that the 100% FCEVs assumed in the CCC projections, to reflect the fact that double decker buses (and buses in highly rural areas) might require gas

UK low emission buses (all single or double deck, no mini-buses)



New buses sales scenario:



'Diesel' refers to a blend of B7 and drop-in renewable diesel, as per the Fuels Roadmap

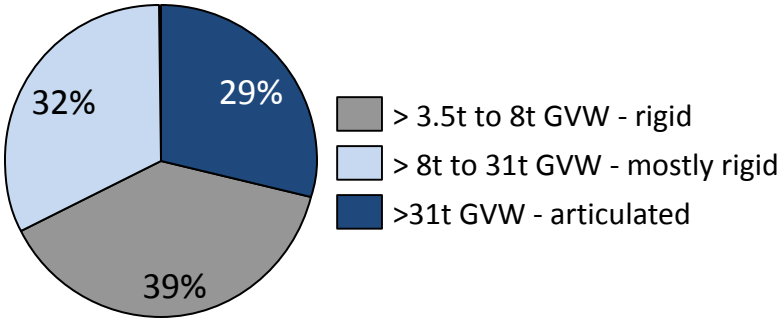
FCEV
(Bio)methane
BEV
Diesel, includes hybrid

Source: Element Energy, DfT Statistics Table VEH0601, LowCVP Low Carbon Emission Bus Market Monitoring (Jan 2015), CCC, *4th Carbon budget*, 2013 1 - Alternative Powertrain for Urban buses study (2012)

For Heavy Goods Vehicles, we tested a high uptake of both electric (battery and fuel cell) and gas trucks

Current UK Heavy Goods Vehicle market

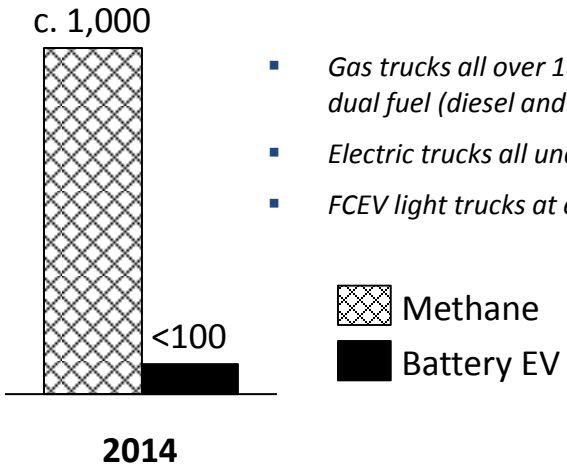
UK HGV fleet, c. 460,000 vehicles:



Scenario

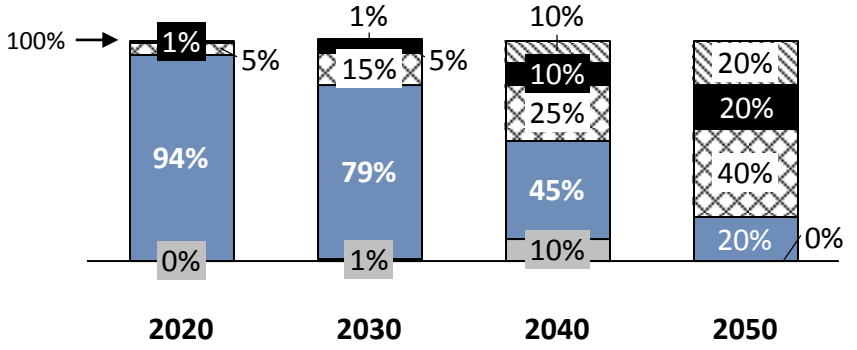
- We to modelled a High Alternative Fuel Uptake case where both pure electric and gas trucks reach a significant sales levels in their respective markets (light and heavy trucks)
- FCEVs also capture a large share of the market, as per the CCC's vision of the role of hydrogen

UK low emission trucks - estimates



- *Gas trucks all over 18t GVW, mostly dual fuel (diesel and methane)*
- *Electric trucks all under 18t GVW*
- *FCEV light trucks at early demo stage*

New truck sales scenario:



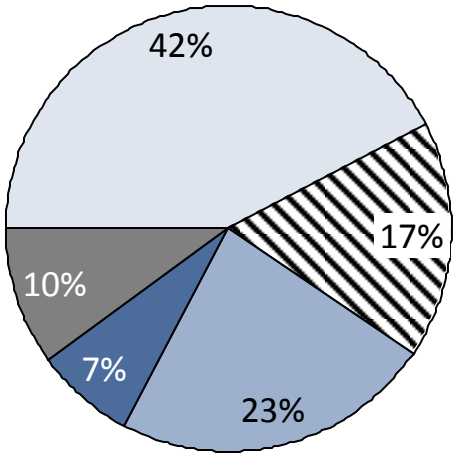
'Diesel' refers to a blend of B7 and drop-in renewable diesel, as per the Fuels Roadmap

FCEV
BEV
Methane
Diesel, includes hybrid
Diesel LPG dual fuel

Source: Element Energy, DfT Statistics, *Birmingham City Blueprint for low carbon fuels refuelling infrastructure*, EE for Birmingham City Council (2015), Low Emission HGV Task Force (2014), HMRC (2014), CCC, *4th Carbon budget*, 2013

Non-Road Mobile Machinery typically refuels in private depots/premises but the case of LPG, liquid air and hydrogen were considered

UK NRMM fleet for industry, construction and agriculture, c. 700,000 units in 2014:



Scenario

- We to considered (qualitatively, considering the lack of disaggregated data on fuel use) the infrastructure impacts of:
  - A transition to Liquid Air for HGV refrigeration units
  - An increase in LPG, battery and hydrogen use for forklifts

Beyond the blending of renewable drop-in diesel in diesel, options for cleaner fuels are:

Agricultural tractors	(Limited options, possibly (bio)methane or high blend biodiesel)
Portable generator sets	(Could transition to LPG, Battery and Fuel Cell packs for some uses)
Other off-roads	(LPG, limited alternative fuel options)
Refrigeration units on HGVs	LPG, could transition to Liquid Air
Forklifts	Use of LPG (already used by c. 30% of forklifts) and batteries could increase, could transition to hydrogen

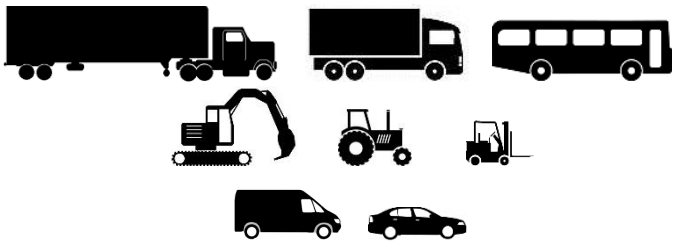
Other off-roads: Telescopic Handlers, Backhoe Loaders, Excavators, Cranes, Bulldozers, Compressors etc.

Source: Element Energy analysis based, on DfT statistics requested in Jan 2015 and *Non-Road Mobile Machinery Usage, Life and Correction Factors* AEA for Dt (2004) , industry input for LPG use in forklift

Appendix – There are broadly two types of refuelling infrastructure for liquid fuels in the UK

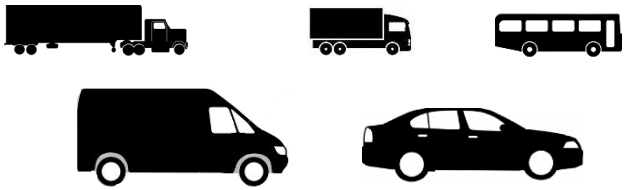
Refuelling at private depots: c.25% fuel sales

- Large fleet operators including public transport operators, hauliers, logistics companies, forklift operators tend to operate designated refuelling depots suited to their 'return to base' operations
- Such facilities tend to be private and exclusively service a single vehicle type
- **Most buses and heavy good vehicles refuel in depots** – share of diesel supplied through depot:
  - 90% for buses, 40% for coaches
  - 80% articulated trucks, 45% rigid trucks



Refuelling at public forecourts: c.75% fuel sales

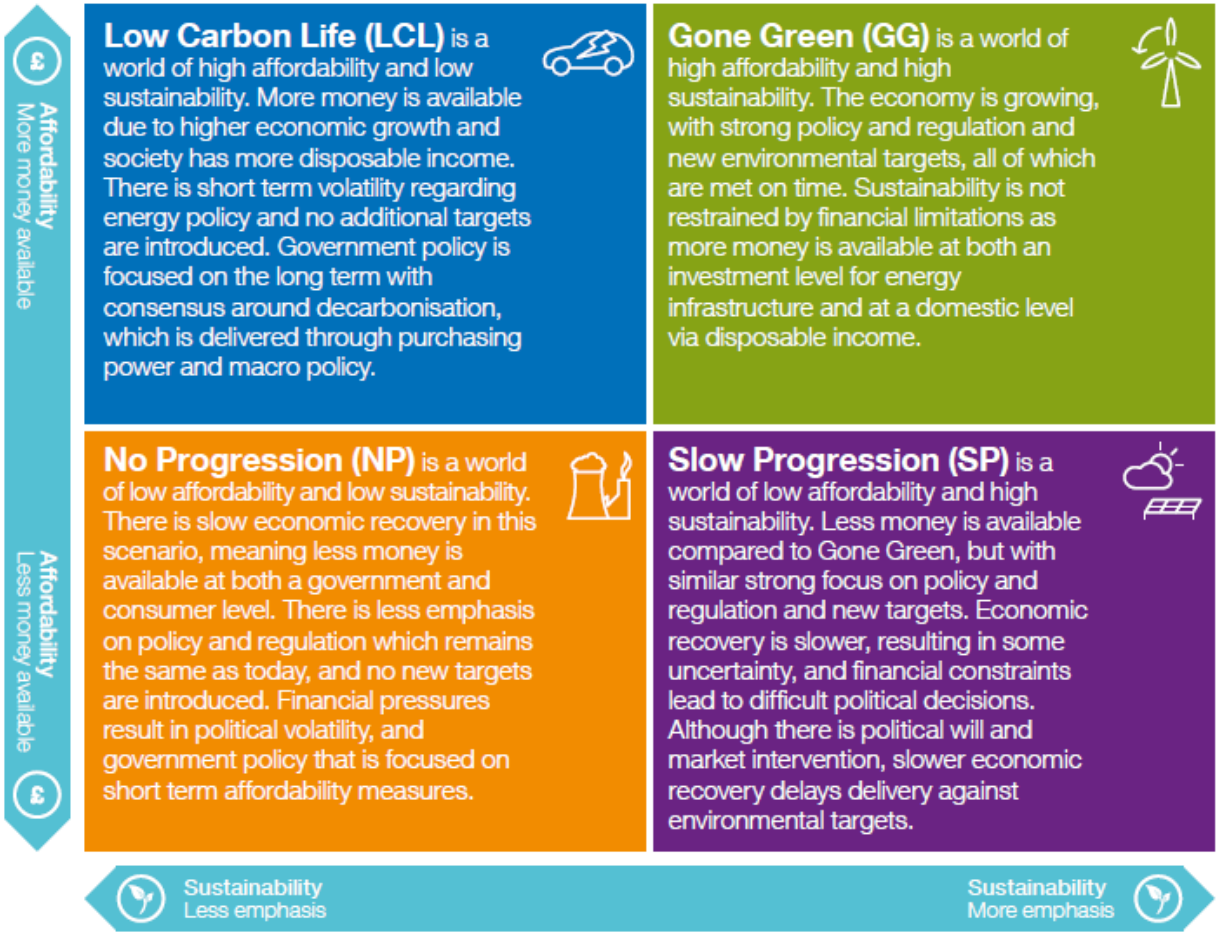
- Generally, public vehicle refuelling (passenger cars, vans, motorbikes, scooters) is facilitated by one of the UK's c.8,600 forecourts
- Refuelling forecourts are publically accessible and are generally owned and operated by large oil companies (e.g. Shell, BP, Esso, etc.), independent retailers and supermarket chains



Source: Element Energy, DfT Modes 3 study (2011)

Appendix – National Grid "Future energy scenarios"

National Grid has developed four scenarios for future electricity generation and gas supply sources to 2050



SOURCE: National Grid "Future Energy Scenarios" (2014)

Appendix – TEN-T Core Network

Source: Element Energy, based on European Commission data

Appendix – methane refuelling station cost assumptions

Natural gas refuelling station capital and civils costs

	CNG		LNG	
Size	Capex	Civils	Capex	Civils
kg/day	£	£	£	£
2,000	£250,000	£80,000	£190,000	£20,000
5,000	£350,000	£120,000	£260,000	£30,000
10,000	£700,000	£140,000	£350,000	£40,000
15,000	1,000,000	£400,000	£800,000	£150,000

'Civils' cost includes planning costs, connection to close proximity gas main, 3 phase electricity, civils and foundation construction

Source: industry input