Transport Energy Infrastructure Roadmap to 2050

LIQUID FUELS ROADMAP

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

JUNE 2015

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Project Steering Group

Autogas Limited
BEAMA
BOC Limited
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
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CNG Services
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Downstream Fuel Association
Drivelectric Ltd.
ENN Group Europe
Gas Bus Alliance
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UPS
Wales & West Utilities

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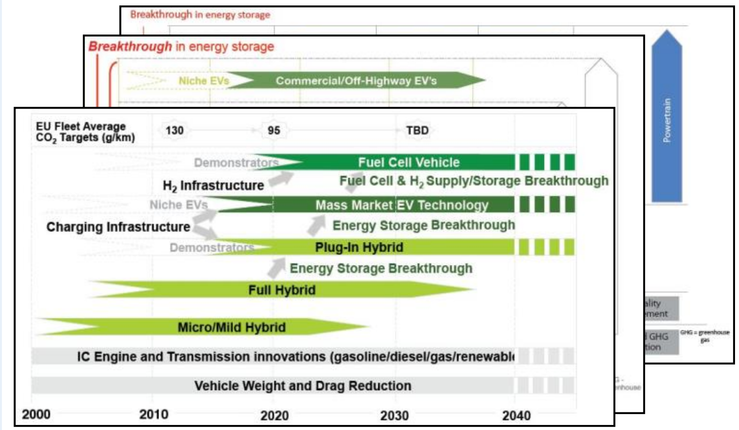
Background - a 'Transport Infrastructure roadmap' is needed to complement existing vehicle and fuel roadmaps

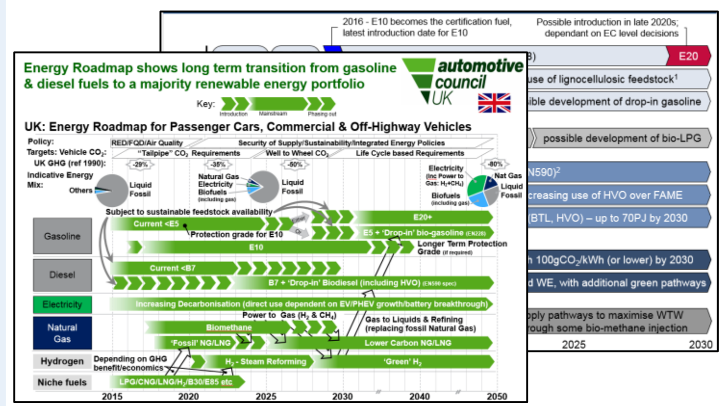
- In the context of the expected transition to lower carbon powertrains and fuels, the **Auto Council vehicle roadmaps** have proven to be a useful tool **to focus research, funding and policy**, bringing into one place the industry's views on future technology options, deployment steps and corresponding 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

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

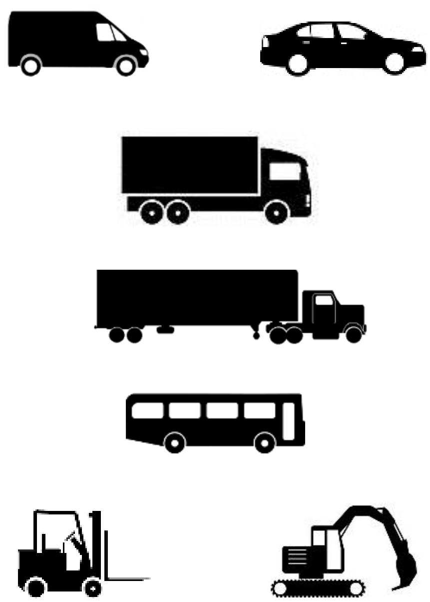
Fuels / energy vectors considered

- 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

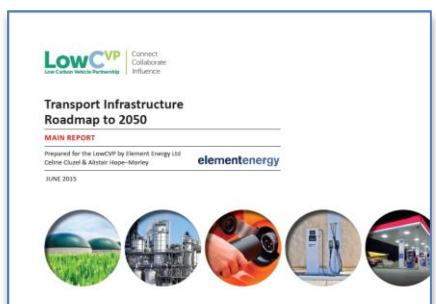
- Workshop themes: **electricity, liquid fuels, methane, hydrogen**
- **38 attendees included**: Infrastructure manufacturers, installers, operators, DNOs, energy companies, fuel suppliers, OEM / vehicle suppliers, end users, local government / regulator

Host stakeholder workshops

Review by Steering Committee

Prepare draft report

Complete final report



Report preparation
External input

Four separate reports have been developed – this report is dedicated to the case of liquid transport fuels

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

Structure of the report

- **Background and status quo**
  - Summary of current upstream to downstream systems and liquid fuel consumption
  - Current supply pathways
  - Current trends regarding forecourts
- **Future infrastructure requirements and barriers to deployment**
  - Quantification of refuelling station needs, by 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 – successful deployment of new powertrains/fuels is the starting assumption*
- **The case of niche fuels**
- **Summary: infrastructure roadmap and recommendations**
  - Roadmap schematic that summarises above findings
  - Recommendations for delivery (national, local, RD&D needs, funding shortfall)

Contents

The extensive national infrastructure supporting the UK's liquid transport fuel demand can be divided into three streams

Upstream

Crude oil → **Crude oil refineries** — Total: 6

Refined products e.g. petrol, diesel, biofuel → **Coastal refined oil import terminals** — Total: 20-30

Midstream

Inland terminals — Total: c.50

Long-term storage
Bioethanol blending

Distribution
51% via pipeline
15% via rail
34% by sea

Downstream

Over 70% of total inland petroleum deliveries are for transport demand

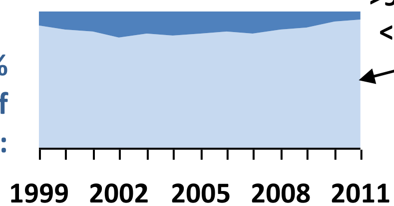
Private depots | **Public forecourts** | **Non-transport demand**

Distribution
>95% via road
<5% via pipeline

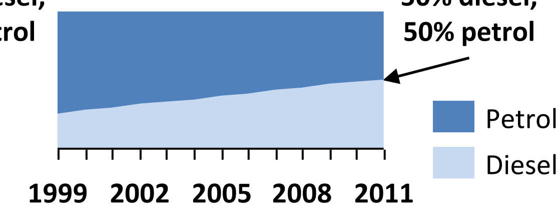
Total delivered petroleum in 2011:

- Private depots: **10 million tonnes/year**
- Public forecourts: **30 million tonnes/year**

Relative % share of consumption:



2011: >95% diesel, <5% petrol



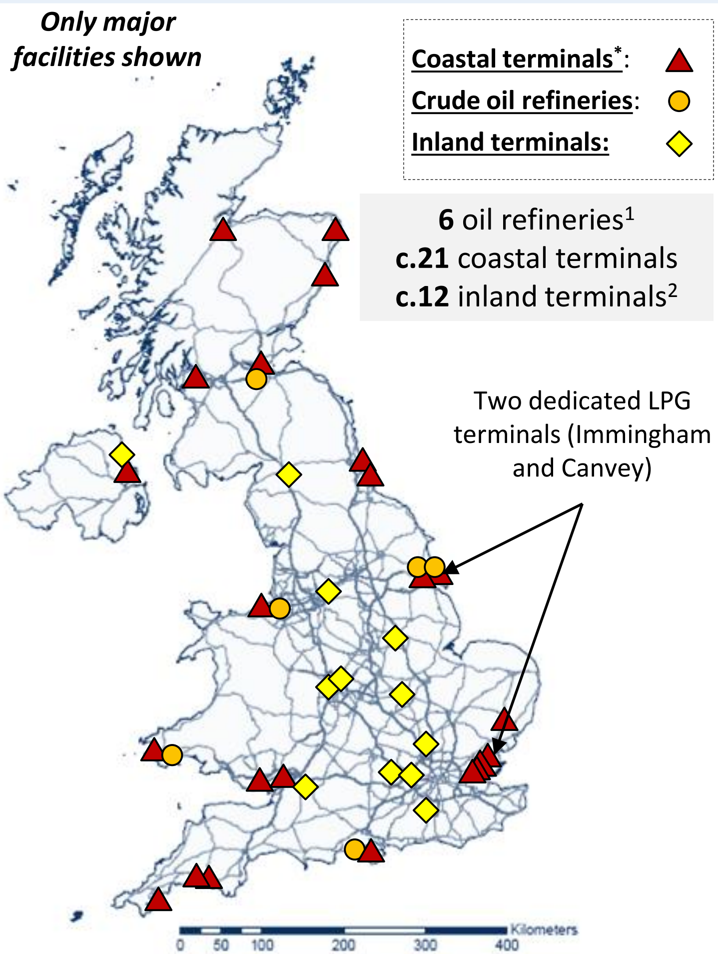
2011: 50% diesel, 50% petrol

Includes domestic heating c.4Mt/year), feedstock for chemical plants (3-4 Mt), lubricating oils and grease (0.5 Mt) and other non-energy products including bitumen, white spirt and coke (c. 2 Mt)

Source: DUKES (2014), DECC (2014), UKPIA (2015), Ricardo AEA (2011)
Mt = million tonnes

All six active UK oil refineries have facilities to import and blend biofuels and LPG

Terminal and oil refinery geography



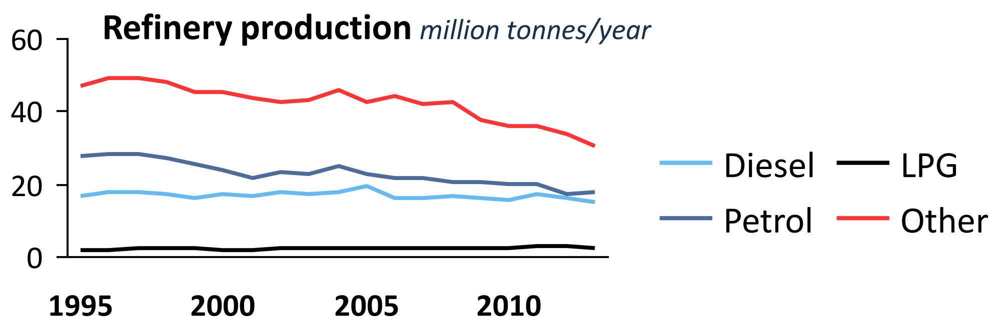
*Coastal terminals include facilities with and without facilities to receive large ship imports

Oil processing and refinery capacity

- The UK's six active oil refineries have a **total refining capacity of c.63 million tonnes per annum** and supply 85% of the inland market demand for petroleum products
- The number of active oil refineries in the UK has **decreased from 19 in 1975 to 6 in 2015**
- Total storage capacity of the UK's c.21 major coastal import terminals is c. 6 million tonnes

UK oil refinery production

- **Refinery production has decreased 30% over the last 10 years** and numerous refineries have closed for commercial reasons
- **Imports have increased**; 40% of diesel demand and c.50-55% of jet fuel demand is imported to the UK



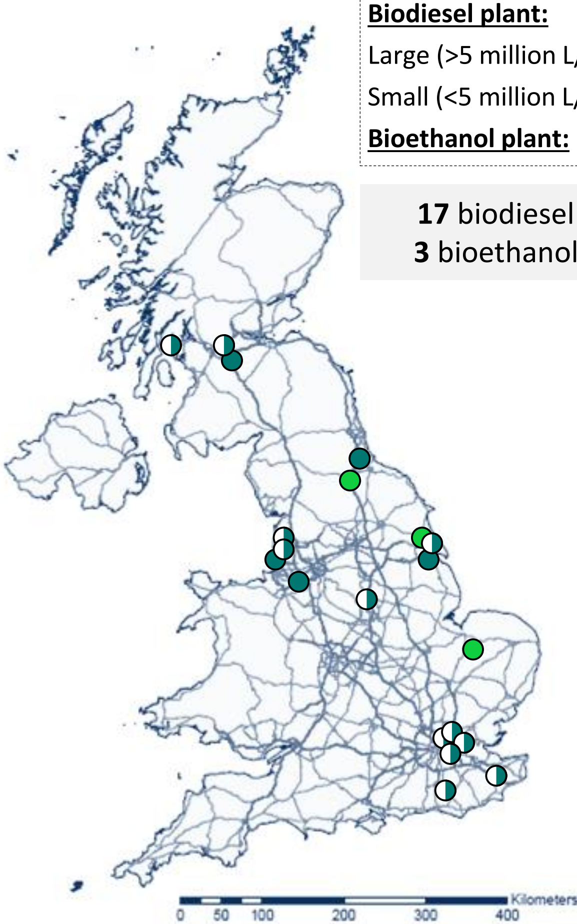
'Other': additional refinery products (e.g. naptha, kerosene, bitumen, etc.)

[1]Excluding dedicated biofuel production plants. [2]Includes privately owned facilities only, excludes government owned facilities primarily used to supply military airfields. Source: Element Energy analysis, UKPIA (2014), DECC (2013)

Generally, FAME is blended at refineries and import terminals and ethanol blended at distribution terminal racks

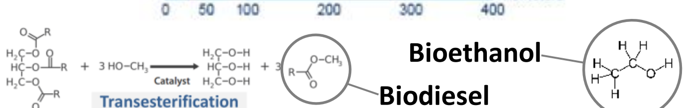
Biofuel

Commercial biofuel production plants

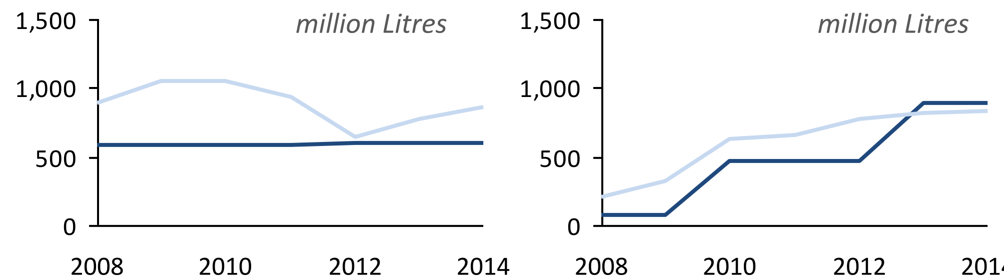


Biodiesel plant:
Large (>5 million L/year)
Small (<5 million L/year)
Bioethanol plant:

17 biodiesel plants
3 bioethanol plants



UK biofuel production and consumption capacity



- The UK has c. 20 dedicated biofuel production plants (total production capacity is c.1,500 million litres/year)
- In 2014, the **majority of FAME was derived from UCO and tallow** (adhering to RED sustainability criteria) but a potential UCO supply shortage could occur as global markets recognise UCO as a cost effective and low carbon feedstock
- In 2014, domestic feedstock supplied 20% of UK biodiesel and bioethanol consumption; the remaining 80% was imported[1]
- ‘Drop-in’ biofuel is unlikely to be available in large quantities until post-2020 due to low technology readiness and investment uncertainty

[1]DECC RTFO Biofuel Statistics (2014). Sources: Ecofys (2013), Element Energy (2014)
FAME = fatty acid methyl esters, UCO = used cooking oil

Road capacity is best suited to deliver higher blends to end users unless demand can justify new pipeline capacity

liquid fuels

Biofuel

- Existing distribution infrastructure delivers **two petrol grades, one diesel and one heating/NRMM grade**
- Introduction of a **new grade** to the distribution system would likely require **displacement of an existing grade**
- Pipeline, road and rail distribution pathways in the UK **all have experience delivering E5-10 and B7 biofuel blends**

Via pipeline

- Bioethanol could potentially **corrode existing pipelines** and is **highly hydrophilic**, therefore is only blended during truck filling at inland terminals[1]
- FAMEs (surface active materials with a propensity to leave residue within pipelines) could **contaminate jet fuels distributed via the same pipeline**[2]
- Costly new infrastructure requires large throughput to repay capital investment

Via rail

- Distribute primary supply from refineries and import terminals to inland terminals, wholesale distributers and large end-user depots (e.g. airports, industry)
- No higher blends (>E5/B7) are currently transported by rail
- Infrastructure is **operating close to full capacity** due to limited loading and discharge points at refineries or terminals
- Rail network is also increasingly limited by **pathway availability**
- Only 3-4 rail loading facilities remain active in the UK

Via road

- Distribute to depots and forecourts through logistics and oil companies
- Road tankers (rigid or semi-rigid) generally comprise **3-6 compartments with varying capacity** (1,000-7,000 litres each)
- Higher blend capability requires **low cost tanker upgrades** (e.g. new seals for >B7, and improved heating/insulation for >E5)
- **Operating close to full capacity** but appetite for expansion exists (e.g. organisations using third-party haulage vehicles have flexible fleet numbers to meet demand variation)

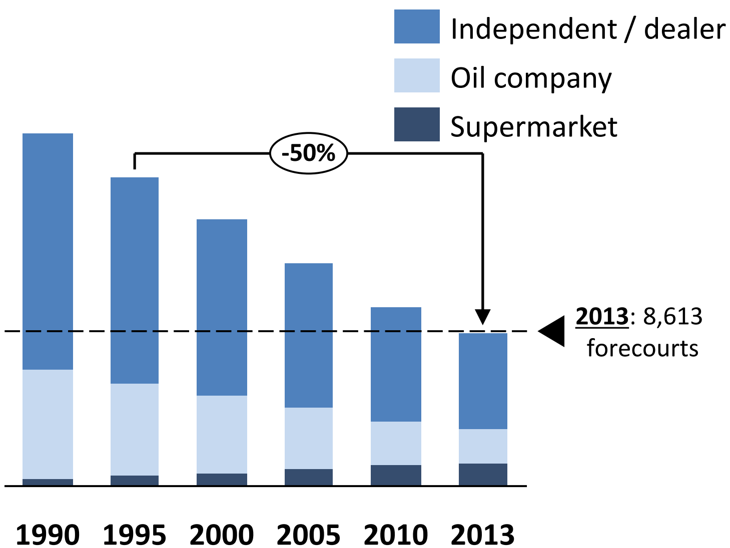
Experience with higher blends (>E5/B7) | Effective capacity for higher blend distribution

[1]Bioethanol derivatives can be distributed by pipeline if converted to ETBE at a refinery by reaction with isobutene, or by producing biobutanol. [2]FAME maximum specification in jet fuels is <50ppm. Source: Ricardo AEA (2011)

Public forecourt numbers are declining and whilst supermarket station numbers are in the minority, their market share of sales is significant

Forecourt numbers

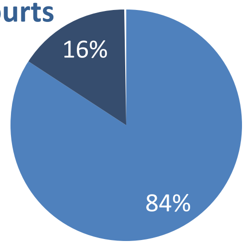
- Overall **fuel demand has declined** due to increased use of diesel and vehicle fuel efficiency improvements
- Total number of forecourts has fallen by 50% since 1995



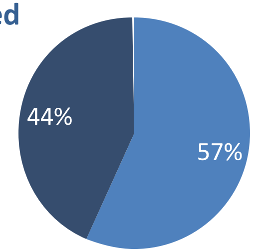
Forecourt operators

- The fuel retail market has experienced a paradigm shift since Tesco opened its first fuel retailing forecourt in 1970, as increasing numbers of larger supermarket forecourts offer lower cost fuel to encourage drivers into stores
- Low prices significantly impact independent retailer business models, resulting in reduced commercial viability, particularly in rural areas where forecourts have fewer pumps and are therefore inherently less profitable

Market share by number of forecourts



Market share by fuel dispensed



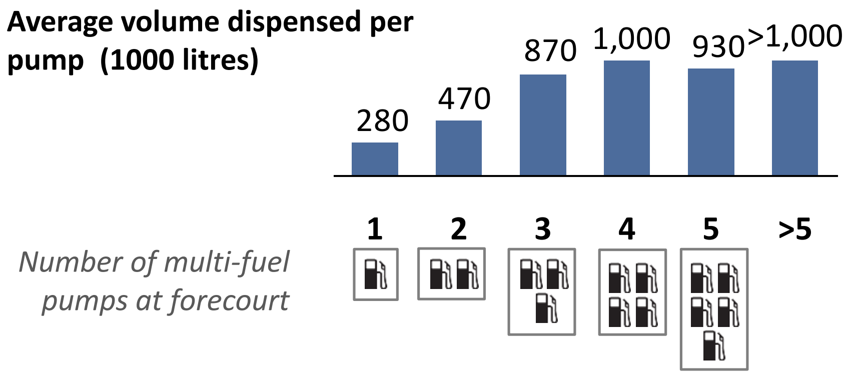
Oil company, dealer and independent retailer | Supermarket

- Supermarket forecourt numbers are increasing and forecourt capacity and average throughput has increased
- Industry feedback indicated that supermarket forecourt geographic coverage is insufficient to supply all UK demand

Source: Experian Catalist (2013), UKPIA (2014)

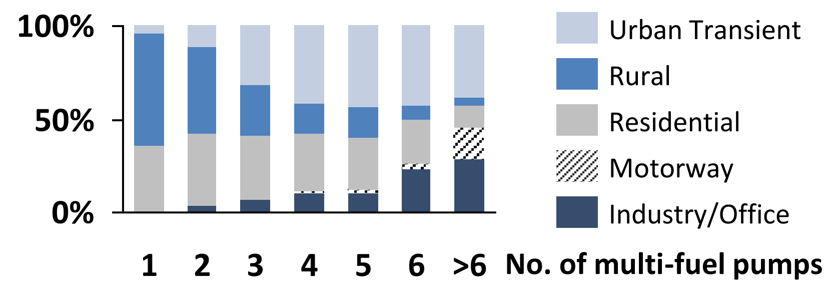
Organisations with the largest market share are technically and economically better suited to sell higher biofuel blends

Forecourt throughput (size dependant)



- Retailers with four or more pumps (65% of UK total) tend have **5-15 times greater volume of sales** than retailers with one or two multi-fuel pumps
- These forecourts generally sell at least three grades of fuel and forecourts with fewer pumps only sell two Therefore retailers with four or more pumps selling 85% of forecourt fuel are more likely to consider offering higher biofuel blends from one of their pumps and incur the associated upgrade costs
- However, many large retailers are not obligated under the RTFO therefore their adoption of higher blend fuels will be governed by customer demand, in turn influenced by Government policy

Forecourt geographic distribution



- >75% of forecourts with fewer than four pumps are located in rural or residential areas
- Availability of **multiple tank and pump combinations** is also essential to station flexibility and the ability to offer higher biofuel blends

35% of forecourts have fewer than 4 pumps (**many located in rural areas**) and are likely to require additional financial support to adopt higher blend biofuels due to their:

- Inherently **weaker economics** (proportionately smaller income)
- **Limited fuel tank capacity** requiring new installations rather than refurbishments

Source: Experian Catalist, Ricardo AEA (2011)
RTFO = Renewable Transport Fuel Obligation

Existing forecourts are compatible with up to E10 only, selling higher blend biofuels (above E10 and B7) would likely require new investment

A) Install new storage and dispensing capacity

- New capacity for higher blends increases the overall forecourt capacity and therefore does not cannibalise any existing output
- However, new tanks are costly and logistically difficult to install on existing forecourts
- Estimated costs for installing new capacity compatible with higher blends of biofuels **£90k-110k/station** (for E85 compatible tank and dispenser)
- Installation of capacity compatible with higher biofuel blends should be strategically timed with licensed decommissioning of old, regular fuel capacity

B) Modify and utilise existing capacity

- Modifying existing capacity is considerably cheaper than installing new capacity but requires partial displacement of a profitable, high demand fuel
- New equipment will be required if existing diesel/petrol capacity is to be utilised e.g. heating/insulation for biodiesel storage and vent/seal upgrades for bioethanol storage. This could be done as part of natural replacement cycle, but this occurs only every 20-30 years
- Any change-of-use for pre-existing tanks to store E85 or B30 will require **dewatering, sludge removal and disposal, filter replacement and flushing of all suction lines** with an estimated cost of c. **£30-40k/station**[1]
- Annual maintenance costs for inspection and cleaning are estimated to be c. **£1-1.5k/year/station**

- Both options have a **cost premium** to the forecourt operator to enable the **retail of less profitable fuel**
- Industry stakeholder consultation (2013/14) showed that a single tank commitment[2] (for forecourts of a particular size) for gradually upgrading to higher blends was a **barrier to adoption due to first mover economic disadvantage**
- **Assurance for vehicle compatibility with higher blends** would be needed before operators consider investment

Source: Element Energy analysis for DfT (2012). [1]See Appendix, [2]Decision by forecourt operator to dedicate (at least) one tank to store a higher biofuel blend, and incrementally upgrade with time.

Private depots generally only have one on-site tank, restricting supply to a single fuel and limiting multi-fuel higher blend trials

HGV depots (demand: c. 8 million tonnes/yr)

- Fragmented depot networks; estimated 2-3,000 private depots in the UK storing biodiesel up to B7
- Majority of depots include single tanks only (restricted to only one blend) but exceptions with high demand have up to 3 tanks
- Require financial incentive, consistent supply and sustainable certification for fleets to begin considering feasibility
- HGVs travel across EU so need consistent fuels

Airport depots (demand: c. 0.1 million tonnes/yr)

- Airport depots store small quantities of biodiesel up to B7 for airside ground vehicles and are believed to be capable of storing higher biofuel blends
- Appetite for higher blends exists but is restricted by concerns over vehicle compatibility

Rail depots (demand: c. 0.6 million tonnes/yr)

- Light maintenance and refuelling depots (c. 50 in the UK) utilise a single pipe network between dispensers and storage tanks (i.e. single-fuel pumps)
- Higher blend biofuels require dedicated storage and dispensing facilities and have been limited to trials in the UK

Coach/bus depots (demand: c. 1 million tonnes/yr)

- More consistent depot networks, with the majority adopting return-to-base operation with single tank sites
- To accommodate higher biofuel blends operators must either refurbish existing tank and run buses on same higher blend of biodiesel (c. **£20k/depot**) or install new storage facilities (equivalent to c. **£2.5k per bus served**)

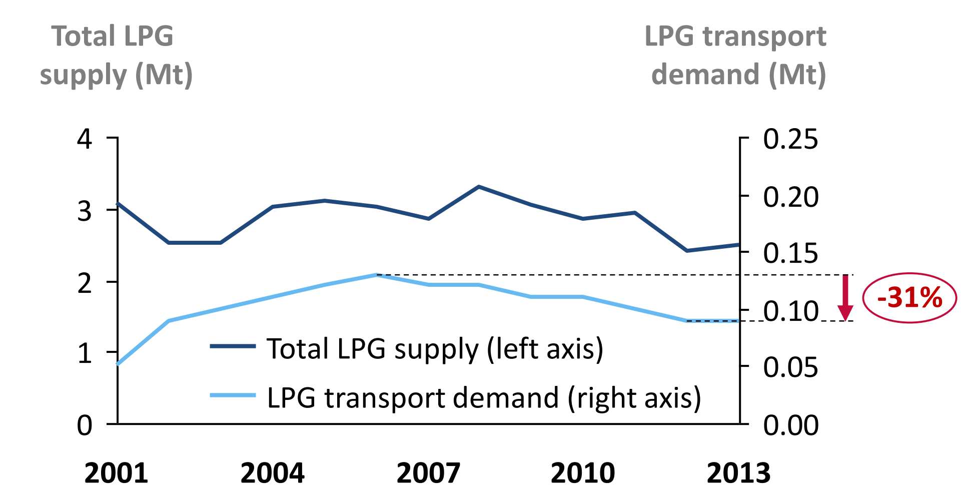
Drop-in fuel = biofuel blend indistinguishable from standard crude-derived fuel

Source: Ricardo AEA (2011), DfT (2014) "Petroleum consumption by transport mode and fuel type"

Despite an extensive infrastructure network, demand for LPG has fallen following the expiry of incentives for vehicle conversion

LPG transport demand relative to total UK supply

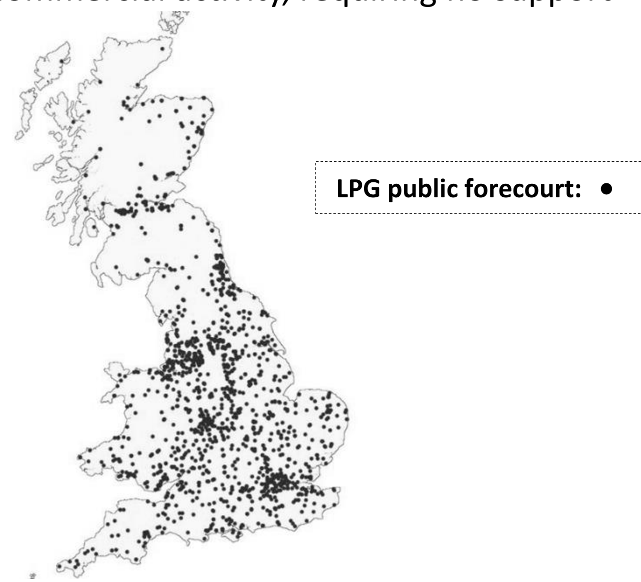
- Between 2001-2006, LPG consumption for transport rose due to attractive **fuel duty incentives** and a vehicle **conversion grant scheme**
- The grant scheme expired in 2006 and the fuel duty differential between LPG and other fuels has diminished
- In 2013, 90,000 tonnes of LPG (4% of total UK LPG supply) was supplied to the transport sector, marking a **31% decline in transport demand since 2006**



Note, DECC's transport consumption figures do not account for all bunkered LPG for forklifts– industry is working with DECC to improve this dataset

LPG transport infrastructure in the UK

- LPG is most commonly used by passenger cars, vans and forklift trucks (FLTs)
- Over **1,400 public selling points** in the UK currently have LPG dispensers
- In addition, over **2,000 private depots** include LPG refuelling facilities for FLTs – an estimated 30% of FLTs in the UK run on LPG
- The current LPG distribution supply chain is a commercial activity, requiring no support



SOURCE: DUKES "Petroleum products: commodity balances" (3.2-3.4), DECC "Energy consumption in the UK" (Chapter 2), industry input. FLT = Fork lift truck

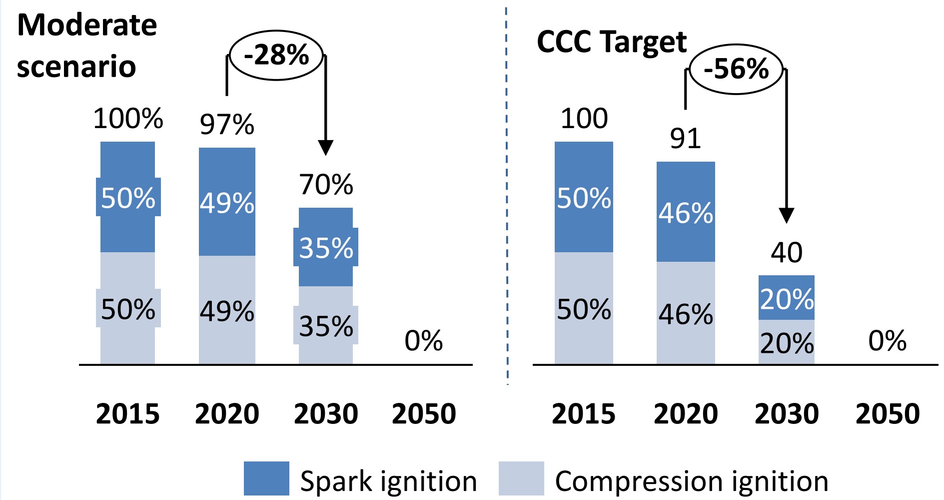
Contents

Due to increasing sales of new powertrains, sales of conventional ICE vehicles are expected to fall significantly beyond 2020

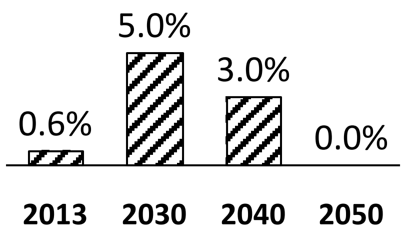
In consultation with the LowCVP Fuels Working Group, we derived uptake scenarios for new powertrains/fuels, they are policy led, typically based on CCC targets. Scenarios are used to forecast infrastructure required to match transport policy ambition and estimate the corresponding upfront costs of this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

- Current split of petrol/diesel engines for new cars (**50/50**) is assumed to remain in the future
- Diesel will be B7 (EN590) with an increasing amount of drop-in renewable diesel – i.e. no compatibility issues to be considered for the distribution infrastructure
- For petrol engines, we evaluated 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
- A decrease of sales of **diesel (hybrid) buses** to 92% in 2020, 80% in 2030 and 0% in 2050
- A decrease of sales of **diesel HGVs** to 94% in 2020, 78% in 2030 and 15% in 2050; some of which are dual fuel LPG (25% substitution rate)

Market share of ICE vehicle sales (new sales)



Share of spark-ignition car (ICE and HEV) stock fuelled with LPG



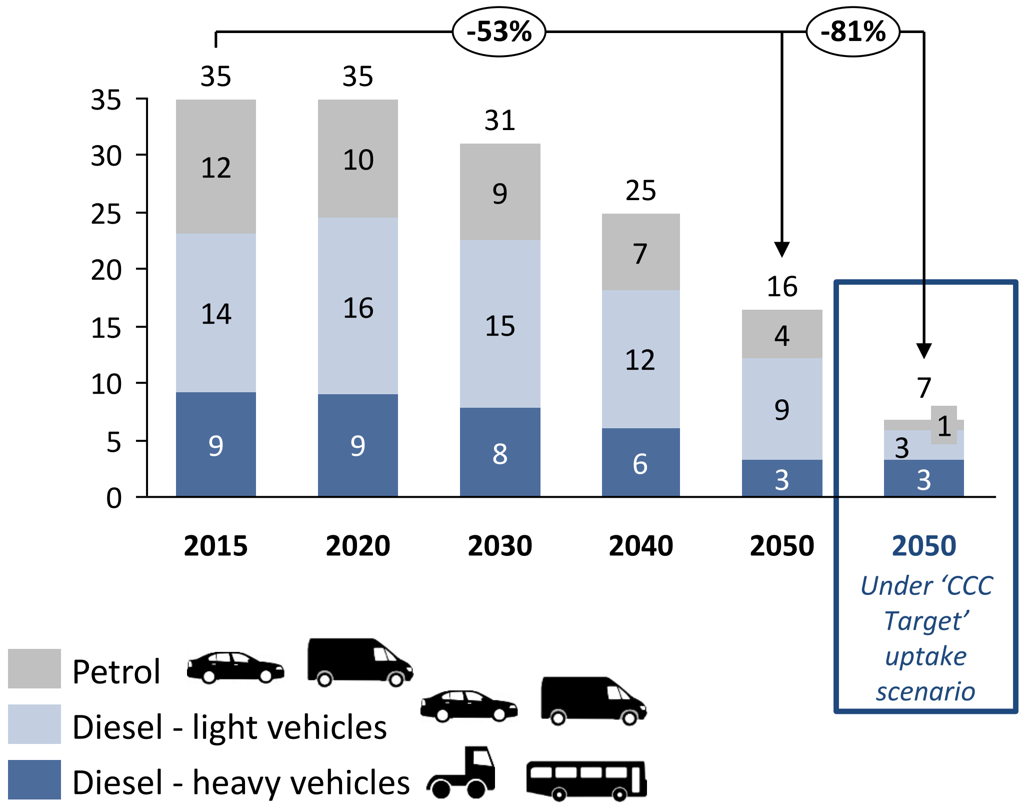
Increasing uptake driven by air quality benefits and fuel cost savings followed by a decline in sales in line with decarbonisation through electric powertrains

See Appendix for more detail on scenarios and sources

Demand for petrol & diesel for road transport will significantly decrease beyond 2020 while use of LPG could increase

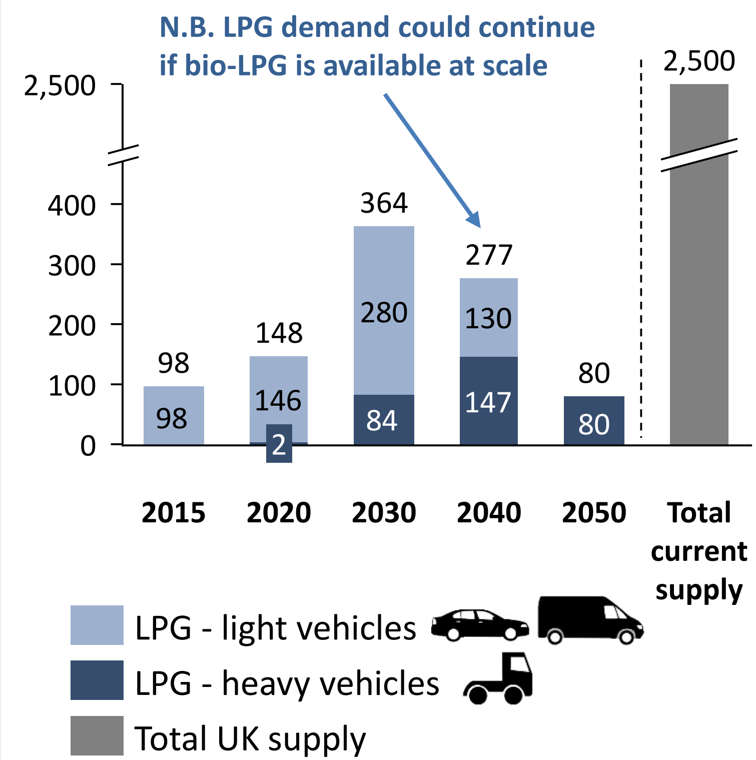
- Depending on the level of uptake of alternative fuel vehicles, the demand for petrol and diesel will decrease by 50 to 80% between now and 2050
- Total LPG demand for transport could increase to c. 360 ktpa under an ambitious LPG conversion/vehicles uptake program

Fuel demand
Million tonnes/year



Fuel demand
Thousand tonnes/year

LPG case

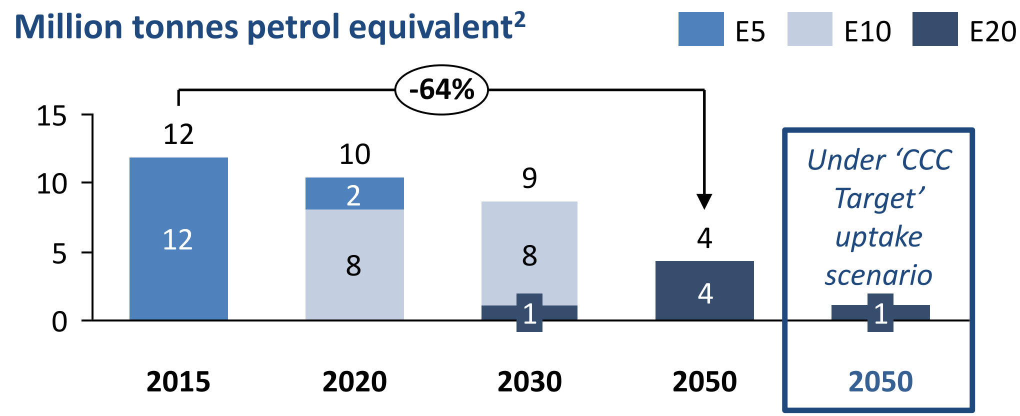


Petrol could transition to E10 before 2020 and to E20 in 2030s while no blends higher than B7 are expected

The case of petrol - forecourt

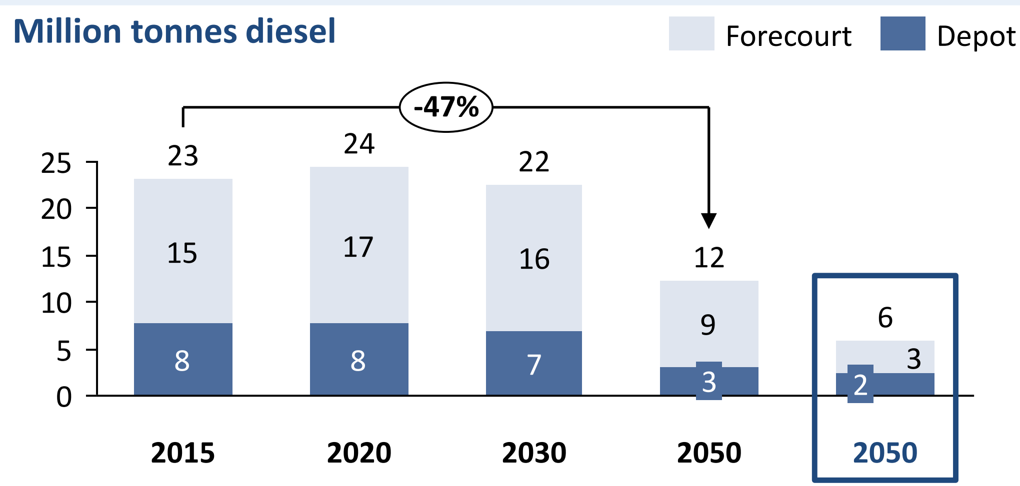
ILLUSTRATIVE SPLIT

- Almost all distributed through forecourts
- According to the fuel roadmap[1],
  - Transition to E10 could be in place before 2020
  - Possible transition (pending EU level actions) to E20 in the 2030s



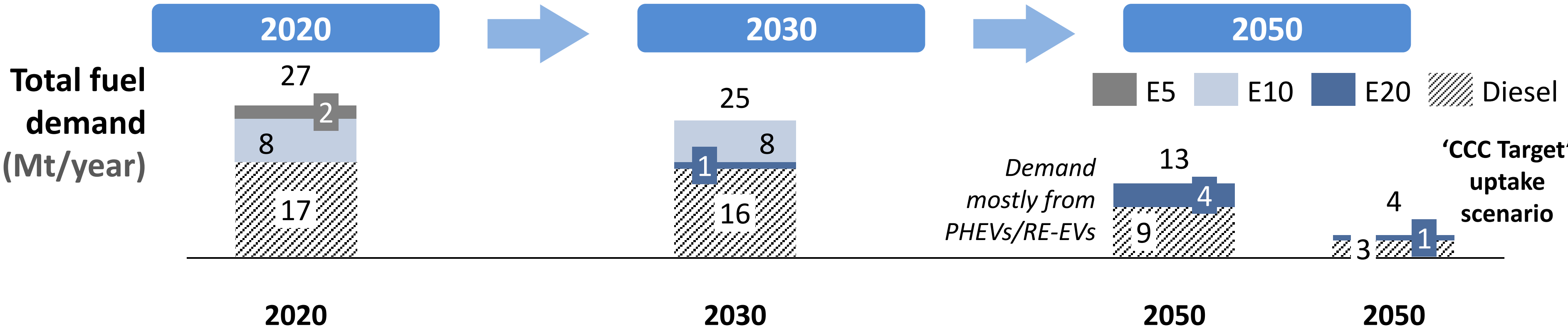
The case of diesel

- Distributed c. 40% in depots, 60% at forecourts
- The projected fall in demand under the high uptake of AFVs translates into: **-80% demand at forecourts and -75% at depots**
- According to the fuel roadmap[1], no higher blends than B7 are expected (but drop-in fuels can increase renewable share)



[1]EE for the LowCVP, UK Transport Fuels Roadmap, 2014
[2]Petrol equivalence accounts for difference in energy density between petrol (43 MJ/kg, LCV) and ethanol (27 MJ/kg, LCV)

The declining fuel demand at forecourts (mostly for light vehicles) is likely to result in further forecourt closures



Expected issues in the short, medium and long-term

- Mechanisms to **support small forecourts in remote areas** will be needed as existing supermarket forecourt coverage is geographically insufficient to supply all UK demand. Under a scenario of extreme demand reduction, the commercial case for urban sites may become challenging if replacement revenue streams cannot be found
- Securing **planning approval for forecourt upgrades** can often be difficult due to environmental concerns and unfamiliarity with new fuels (e.g. tank upgrade or new tank for high blends)
- Delays in approval process could **accelerate forecourt closures**
- Infrastructure adjustments to cope with **declining demand will be market driven**
- Associated **safety risks of multiple fuel coexistence** at a single forecourt need to be better understood
- British standards for new biofuels can be adopted through **EU frameworks to ensure technical compatibility**
- Drivers should be **informed of fuel availability via a communication system** as fuel choice become more diverse
- Impact of reduced demand on the **continued decline in domestic refinery production** is being addressed by DECC's Mid Stream Oil Task Force

Source: EE fleet model, based on uptake scenarios presented in Chapter 1 (Introduction and context)

Tanker distribution is well suited to delivering higher blend biofuels but incentivising infrastructure operators to invest will be more difficult

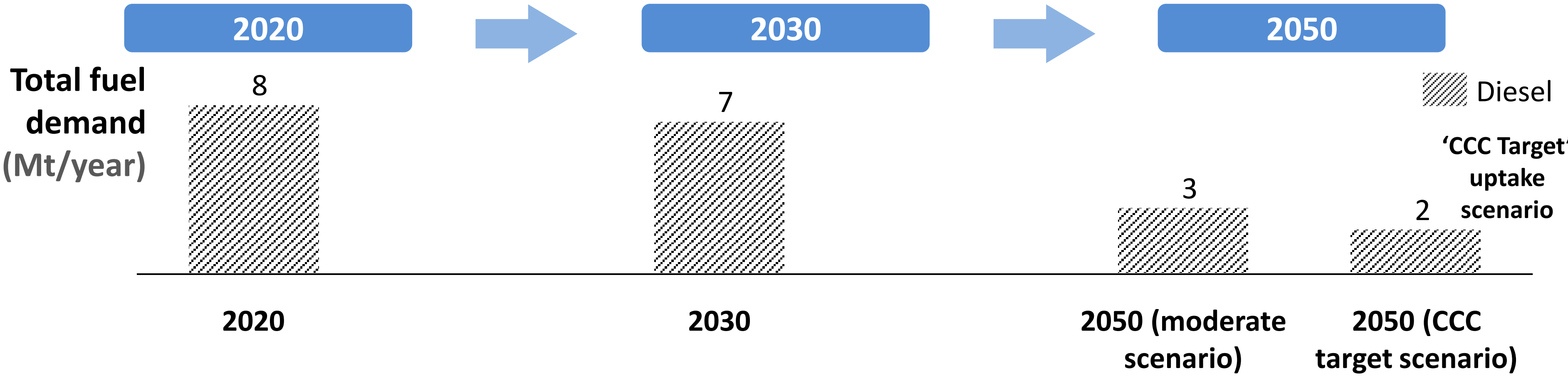
liquid fuels

Forecourts | E10/E20

Barrier	Description	Example solution
Costs for installing new station capacity	Civil works and installation of new equipment can cost up to **c.£100k per station**	Storage tanks, dispensers and pipework are fully commercial technologies with **little opportunity for significant cost reduction**
Costs for upgrading existing station capacity	Refurbishment of existing equipment can cost up to **c.£10k/station**	Dedicated financial support?
Lack of confidence for vehicle compatibility with higher blends	Operators will not invest in higher blend infrastructure unless **national vehicle compatibility** is understood/in place	Infrastructure operators require clear dialogue from vehicle suppliers
Lack of confidence in long term viability	Uncertainty of biofuels policy and **growing competition from alternative fuels** creates strong demand risk for investors	Long term visibility of dates for minimum biofuel blends at forecourts?
First mover commercial disadvantage for adopting higher blends	Forecourt upgrades are needed for E20; investment necessitates **displacement of regular, more profitable fuel sales**	Single tank commitment legislation
Commercial non-viability of small throughput forecourts	Small/independent retailers are already under strain and this affects rural areas more; investment to transition to E10/E20 might not be viable without support	Dedicated strategy to maintain forecourts in some areas (likely rural areas in short term but more widespread issue over time)
Limited rail pathway capacity	Fuel delivery by rail is being increasingly displaced by competing services for rail pathways from e.g. passenger trains	Dedicated rail pathway (capacity) for transport fuel distribution

Source: Ricardo AEA (2011), Element Energy analysis

Although blends higher than B7 are not expected at forecourts, private depots can adopt higher blends



Expected issues in the short, medium and long-term

- Depot fleets are **increasingly utilising public forecourt facilities** with fuel cards instead of depot facilities
- This shift in operation is driven by the elimination of many, often cumbersome, responsibilities associated with the management of bunkered fuel at depots (e.g. mitigation of leakages to avoid environmental damage, theft prevention, general maintenance)
- Demand from fleets through fuel cards effectively maintain many trunk road forecourts by providing a 'base load' and associated spending (e.g. at the kiosk). A further move away from depot refuelling to fuel cards could support forecourts, however, this benefit is likely to be outweighed by the overall decrease in fleet fuel demand
- While blends higher than B7 are not expected at forecourts[1] , captive fleets might choose to adopt higher blends which can be delivered to depots by road tanker, e.g. C.120 buses are already running on B20 in London

Estimate of demand based on share of buses, trucks and vans refuelling through bunkered supply at depot – does not include the demand from Non Road Mobile Machinery [1]Based on the LowCVP EE Fuel Roadmap and AutoCouncil Energy roadmap

Under an ambitious conversion program for cars/vans, the LPG public network would have to increase significantly

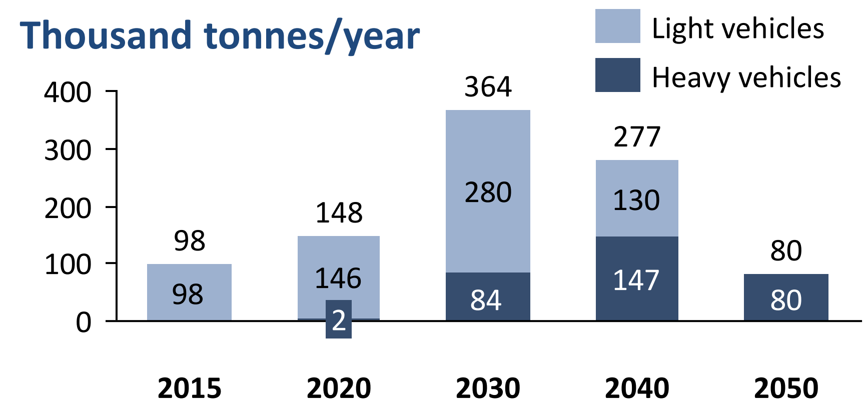
liquid fuels

LPG

Network to support increased demand

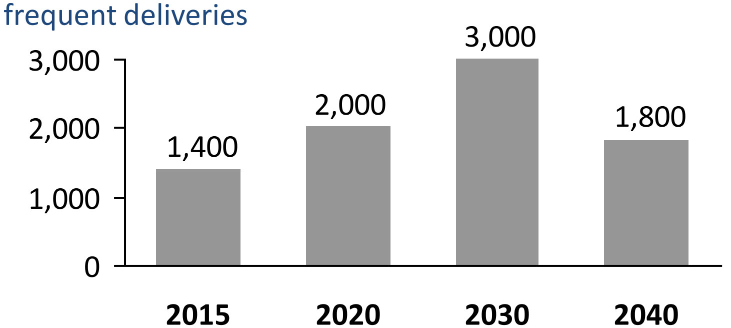
- Under the LPG uptake scenario[1], demand for LPG at public forecourt could **increase to c. 280 kt by 2030**, from under 100kt today
- To deliver this demand, the network of public LPG selling points would need to **increase from 1,400 to c. 3,000.** These might be mainly non-forecourt installations as they are cheaper and quicker to commission (Code of Practices in place[2] but fewer restrictions than a forecourt integrated dispenser)
- New investment to deploy new LPG selling points will be entirely market driven but will also require **commitment signal from UK government for use of LPG in transport**
- Biopropane is expected to enter the UK market in the short term however, as a **renewable 'drop-in' fuel for conventional LPG**, it will not require any infrastructure upgrade
- Trucks and Non Road Mobile Machineries (forklifts, refrigeration units, etc.) refuel in depots – there are no particular infrastructure challenges for a transition to/increase use of bunkered LPG

Forecasted LPG transport fuel demand



Corresponding public LPG selling points

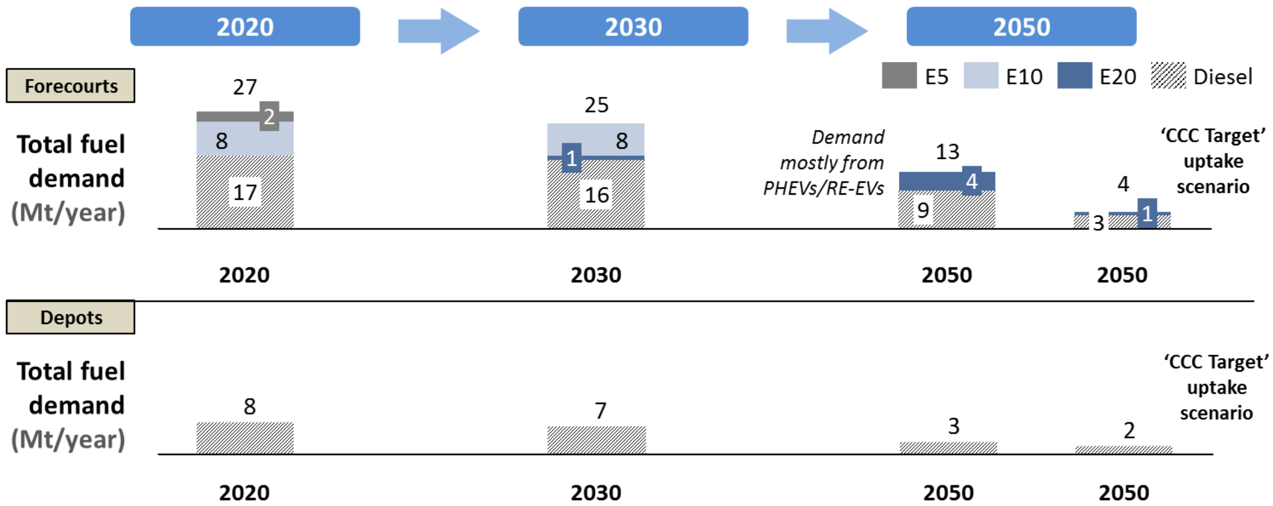
Assuming an increased in average throughput through more frequent deliveries



LPG demand projection as per described in slide 19. Assumes heavy vehicles would refuel at depot

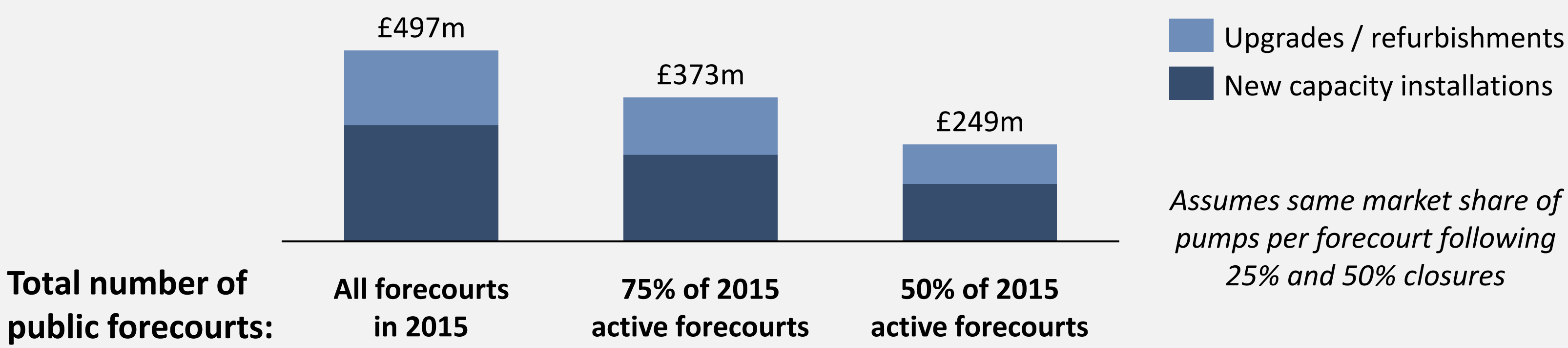
Estimate of demand does not include the demand from Non Road Machinery. Source: EE for UKPLG (2013) 1- Driven for example by incentives recognising its air quality benefits 2- see www.uklpg.org/shop/codes-of-practice/

Approximately £500 million would be required to adapt the current UK public forecourt network to be compatible with higher biofuel blends



Scenario where all forecourt petrol demand is met with E20 by 2050

Approximate level of infrastructure investment required for a transition for all public forecourts to adopt a single tank commitment for a higher blend biofuel (e.g. E20)



Assumes same market share of pumps per forecourt following 25% and 50% closures

Assumptions: upgrade cost = £35k/site, capacity cost £100k/site (Source: Element Energy for DfT, 2012), 65% of existing forecourts have 3+ pumps and separate storage tanks, remainder have <3 pumps and storage tanks.

Contents

There are a number of fuels currently not used in the UK transport system that could have a role in future

The case of three niche/future fuels were investigated in consultation with industry:

Methanol

- The introduction of preferential fuel duty (expected early into the next Parliament) could stimulate the development of heavy duty vehicle engines working on high blend methanol
- The UK-based company ZeroM is currently working on this concept
- There is already a bio-methanol supply chain, albeit for low blend applications

Liquid Air (LAIR)

- Recent studies have outlined the potential for Liquid Air in refrigeration applications as well as hybrid power systems
- Three UK based companies have developed LAIR engines
- Existing production of liquid nitrogen can be used in the short term before transitioning to liquid air
- OLEV will support Dearman Engine's development of a prototype power and cooling system for refrigerated trucks and AC buses (as part of an £11m funding scheme to support UK innovation)

E85

- Other countries have successfully deployed flex-fuel vehicles, which can operate on gasoline as well as on E85 (up to 85% vol. blend of ethanol with gasoline), notably Brazil
- Techno-economic modelling studies suggest E85 is one of the most cost-effective ways of increasing the share of renewable energy in transport fuels[1]

1 -*Options and recommendations to meet the RED transport target*, Element Energy for LowCVP (2014)

AC = Air conditioned

Methanol is produced from natural gas, coal or biomass and can be used as a petrol blend, neat or to produce MTBE and biodiesel

Production of methanol is mainly from fossil fuels but it can be made from renewable sources

- Methanol is mainly produced from fossil fuels such as natural gas or coal
- Bio-methanol is produced from renewable resources e.g. agricultural waste, wood
- Can also be made from captured CO_2
- When produced from fossil fuels, costs are comparable to petrol and diesel on an energy basis while bio-methanol costs are 1.5-4 times higher[1]

Methanol is used as a feedstock for various products and can also be used in transport

- Chemical feedstock for e.g. plastics, synthetic fibres and paints
- In transport, it is used in various ways:
  - Directly as a fuel or blended with petrol
  - Converted to DME, a diesel replacement
  - Converted to MTBE, a blend component of petrol
  - As part of the biodiesel production process
- Methanol fuel cells are being developed, though main industry focus is on pure hydrogen systems

SAFETY

- Blends of petrol and methanol have an increased vapour pressure
- Methanol is relatively low intrinsic toxicity but it is metabolised into highly toxic compounds (e.g. formaldehyde and formic acid); ingestion of c. 50ml can cause death if not treated
- Finland tried to secure an EU-wide ban on the use of methanol in multiple products (e.g. windscreen washer fluid) but the request has been rejected
- Offers similar fire safety challenges to ethanol
- More difficult to ignite than petrol, burns slower and with a cooler, invisible flame

[1] Production of Bio-methanol, Technology Brief (2013)

Source: Energy Carriers for Powertrains, ERTRAC 2014, Euro Care (2015)

The UK demand for methanol is currently small though its viability for use in fuel is demonstrated by its popularity in China

Global methanol production in 2013 was c. 45 Mt/year[1]

UK

- The government is expected to legislated early in the next Parliament a reduced fuel duty of 7.90 p/l to aqua-methanol (which cannot be blended in petrol)
- The difference between a-methanol rate and the main rate will be maintained until 2024 (reviewed in 2016)
- EC Fuel Quality Directive limits the percentage of methanol in petrol to 3%, with further limits on total oxygenates[3]
- Approximately 34.5 kt of bio-methanol were blended in gasoline in the UK in 2013-14[2]

China

- China's total methanol consumption in fuels was 11 Mt in 2013, including 4.6Mt used in vehicles and 7Mt used for dimethyl ether
- China produces methanol mainly from coal, making it cheaper than imported petroleum fuels
- 160,000 vehicles in China have been modified to run on methanol fuel blends
- A Chinese national M15 standard is being prepared and many local standards are already in place

US

- In US, large scale tests in California in 1980s-90s demonstrated methanol's viability
- Dedicated and flexible fuel vehicles were deployed and refuelling infrastructure was installed
- Lack of economic incentive (low petrol price) and lack of political advocacy led to methanol's failure to become a significant transport fuel in the US

[1]Production of Bio-methanol, Technology Brief (2013), [2]RTFO Biofuel Statistics (2014),[3]Directive 2009/30/EC. Sources: Methanol Institute Blog (12-09-2014), Bromberg and Cheng (2010)

Transportation of methanol would be mainly by truck and adaptation of refuelling infrastructure would require investment

Forecourt storage and distribution

- Methanol is corrosive to many materials but is compatible with stainless steel, carbon steel and methanol-compatible fiberglass
- For storage at retail service stations, new underground tank storage may be necessary
- Existing tanks can be converted by thorough cleaning and, where necessary the use of a methanol-compatible liner
- Pumps and piping used to move methanol from the storage tank to the dispenser must be made of methanol-compatible materials
- Dispensers used for petroleum fuels typically include elements that are methanol incompatible (aluminium, brass, elastomers) so specially developed dispensers must be used to avoid leaks
- Conventional nozzles designed for methanol are available, as is a spill-free nozzle developed by the Methanol Fuel Cell Alliance

Transportation

- Methanol typically shipped by railway tank car, barge and truck tanker
- In the US some is sent by pipeline (over very short distances)
- There are difficulties with using pipelines usually used for other petroleum products for shipping methanol
  - Degradation by mingling with other products
  - Methanol will remove water/residues in the pipeline
  - Pipelines can be converted by cleaning, though there may be material compatibility issues
- Assuming 5% of total HGV energy demand by 2050, 0.6 million tonnes of methanol could be consumed in the UK[1]

Source: Use of Methanol as a Transportation Fuel, The Methanol Institute, 2007

[1]Methanol energy content = 20 MJ/kg (lower calorific value), Total HGV energy demand in 2050 = 264 PJ

Liquid air engine technology could offer significant benefits, particularly in refrigeration of trucks and trailers

Various liquid air engine technologies have been proposed, of which the Dearman engine is the most mature

- The Dearman engine uses the rapid expansion of liquid air as it comes in contact with a warm heat exchange fluid to power a piston engine
- This can be used in three configurations:

For refrigeration in a 'power and cooling' configuration (TRU for vans, lorries, trailers, shipping containers)	As a heat hybrid, using excess heat from an ICE (suitable for buses, coaches, lorries, urban delivery vehicles)	On its own, drawing heat from the environment (suitable for short range, low power requirement vehicles such as fork-lift trucks)

- Other engines using liquid air have been proposed including the Ricardo split cycle liquid nitrogen engine and the EpiQair rotary liquid air engine

Refrigeration

- Refrigeration in vans and small trucks is provided by the main ICE, while for most larger trucks and trailers it is provided by an auxiliary ICE
- Most refrigerated trucks and trailers use red diesel auxiliary engines, whose emissions are currently unregulated and untreated, and can account for over 80% of NOx and PM emissions despite accounting for only 20% of the overall fuel consumption
- Using liquid nitrogen ($N_{2(l)}$) evaporation for refrigeration is being trialled in 6 vehicles in the UK (1000 worldwide), though this requires ancillary power from the main engine, increasing its diesel consumption
- The use of a Dearman liquid air engine would offer improved efficiency over $N_{2(l)}$ evaporation as it would produce both cooling and shaft power
- A prototype is currently in testing and small series production is due to begin in 2016[1]

[1]Dearman Engine Company. TRU: Transport Refrigeration Unit

Source: Liquid Air on the Highway, Liquid Air Energy Network, 2014

Large volumes of spare liquid nitrogen production capacity exist in the UK, within delivery distance of all major cities

Liquid air is not currently produced in the UK (liquid nitrogen will be used)

- Liquid air is not yet produced commercially, but liquid nitrogen (LIN) is widely produced and can be used for similar applications
- LIN is produced at c. 10 Air Separation Units (ASUs) in the UK via an energy intensive process, generally run during off peak electricity hours
- According to the Liquid Air Energy Network report, using these facilities during the day could provide 2,200 tonnes of LIN per day
- Major industrial users are supplied by pipeline while other customers are supplied by road tanker – most large cities are within the distribution range of one or more LIN production sites
- LIN is still routinely delivered to areas outside those covered on this map, but costs may be higher
- An operator would need to rent a cryogenic tank and pump in order to store and dispense LIN

- DECC will support a project to demonstrate a 5MW/15MWh Liquid Air Energy Storage (LAES) system, due to start operation in 2015 in Manchester (led by Highview Power and Viridor)
- Highview have successfully piloted their energy storage concept at a 350kW/2.5MWh plant with SSE since 2010
- This new project will assess the potential for liquid air technology to address grid-scale energy storage needs and support the integration of intermittent renewable generation

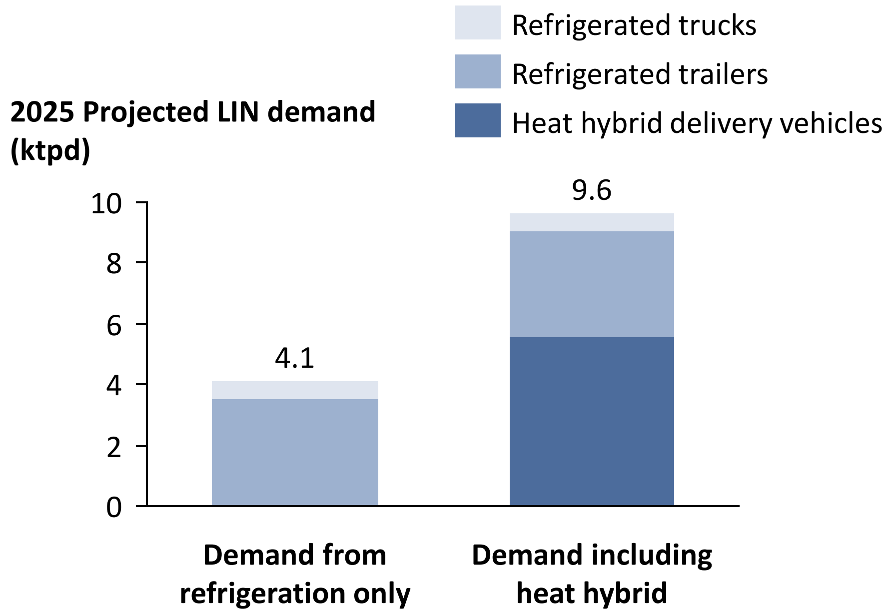
Current UK locations with spare LIN production capacity with indicative delivery radius (c.350km)

Source: Liquid Air on the Highway, Liquid Air Energy Network (2014), DECC press release "£8 million boost for energy storage innovation" (13/02/2014)

Sufficient production capacity exists for early deployment and future new capacity could exploit 'waste coolth' from LNG regasification

Future demand

- There is sufficient spare production capacity for pilot schemes and early deployment
- The Liquid Air Energy Network report predicts that consumption of LIN will be 4.1 ktpd for refrigeration alone in 2025
- This implies the need for installation of liquefaction capacity for an additional 1.9 ktpd LIN or liquid air by this date
- Production of liquid air is cheaper than LIN production and consumes 20% less energy, as there is no need to separate the component gases
- The Liquid Air Energy Network report suggests that if there is widespread take-up, new capacity would be required soonest in East London and the West Midlands
- In Japan, ASUs are being linked to LNG regasification terminals to use their waste 'coolth' to improve liquefaction efficiency (using two thirds less electricity)
- This would be possible in the UK at its three LNG input terminals where re-gasification takes place



Policy/Regulation issues

- Regulation of emissions of auxiliary diesel engines used for refrigeration would encourage the uptake of low emission replacements
- Liquid nitrogen is currently seen as an energy intensive industrial commodity and is taxed accordingly, a situation which could be amended to support its use in transport

Source: Liquid Air on the Highway, Liquid Air Energy Network, 2014

Contents

With a predicted demand decrease for liquid fuels, forecourts may have to integrate new fuels and/or receive support in certain locations

Infrastructure roadmap

2015 | 2020 | 2025 | 2030 | 2050

Legend: Cost; Stations; Technical

Public forecourts

- Coverage:
  - Continued slow rate of closures from c.8,600 stations
  - **Support measures for some areas might be needed to maintain network**
  - Dependent on feasibility of multi-fuel integration and/or specific support mechanisms
- Integration:
  - Trial integration of multiple fuel infrastructures
  - Increased coexistence of multi-fuel infrastructure to maximise utilisation
- E20 forecourt investment:
  - *Potential transition to E20 would require upgrades to existing forecourts*
  - c. £250m-£600m investment required for upgrades and capacity installations

Private depots

- Diesel: Growing proportion of bunkered demand will shift to utilise forecourts with fuel cards
- Niche fuels:
  - Operators trial niche fuel with small numbers of fleet vehicles
  - Key findings from trials inform future operator investment
- LPG: c.2,000 — **Depot infrastructure fully commercial – growth to follow demand**

Public selling points

- LPG: c.1,400 — c. 2,000 — **Infrastructure growth entirely market driven** — c. 3,000

Liquid fuel vehicle stock

Projections are based on policy-led uptake scenarios presented on page 21

Uptake scenarios informed quantification of infrastructure requirements

By 2050 cars are mostly RE-EVs / PHEVs

Thousand vehicles	2020	2025	2030	2050
Cars	30,000	32,000	32,000	6,000-31,000
Vans	4,000	4,300	4,300	1,000-5,000
HDVs	700	700	700	360

50-80% decrease in fuel demand on 2015 levels

Dashed lines represent high uncertainty

Major milestone /enabler

Delays to planning to modify forecourts should be minimised to avoid investor uncertainty and financial support may be needed in certain areas

1 Station economics and support

- Steep decline in demand beyond 2030 is likely to significantly impact commercial viability of fuel retailing (particularly for small public forecourts located in rural areas of the UK to start with, but more widespread issue in long term)
- A transition to a higher biofuel blend will require large investments for tank replacements and/or upgrades

Recommendations

Central Government: Consider mechanisms to ensure minimum filling station coverage, particularly in rural areas

Local Authorities: Identify any local supply shortages and forecourts most affected by declining fuel demand

2 Planning permission guidance

- Acquiring planning permission to upgrade existing forecourt facilities can often be delayed or rejected
- Delays for upgrade approval can cause partial unavailability and negatively impact commercial operation, thereby directly accelerating forecourt closure, particularly for underutilised areas

Recommendations

Central Gov. and LAs: Work with regulators to identify common causes of delays and improve planning permission guidelines as appropriate

3 Innovation opportunities

- Biodiesel and bioethanol require additional handling considerations
- Higher bioethanol blends can damage regular refuelling facilities by causing stress corrosion cracking of steel and degradation of elastomers, therefore significant investment will be required to upgrade existing infrastructure

Recommendations

R&D bodies: Investigate cost reduction opportunities for station upgrades to handle higher biofuel blends

Source: Element Energy

As declining liquid fuel demand causes station closures, facilitating optimal use of remaining forecourts is likely to be required

4 Multi-fuel infrastructure integration

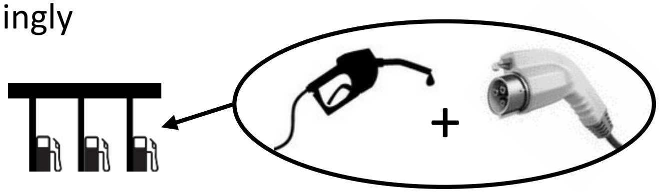
- The transport system is expected to be decarbonised through multiple alternative fuels / energy vectors
- Existing forecourts are strategically sited to optimally service driver needs by major roads and junctions
- Co-locating infrastructure for multiple fuels at forecourts could ensure utilisation is maintained

Recommendations

Regulators: Develop standards for co-locating multiple infrastructures and work with central government to develop planning guidance for Local Authorities

R&D bodies: Identify technical barriers to co-locating multiple infrastructures (e.g. high power rapid charge points adjacent to liquid fuels)

Industry and gov.: Liaise with APEA to update Blue Book[1] accordingly

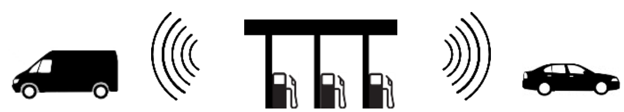


5 Communication of forecourt availability

- As forecourt closures continue (and new blends are introduced), there will be an increasing need to ensure drivers can easily access information detailing station & blend availability and location
- Communication systems to inform drivers of real-time fuel availability at nearby public forecourts supported by a national database could be developed
- Central coordination of software development will ensure a consistent interface between drivers and public infrastructure e.g. allowing use with existing navigation system providers

Recommendations

Industry: Develop communication system



[1]National Guidance document jointly published by the Energy Institute and Association for Petroleum and Explosives (APEA) used to assess and sign off the safety of new forecourt installations and upgrades

Liquid air has the highest potential and developing a distribution infrastructure for transport might require investment in UK skills

Methanol

- Consulted industry stakeholders are doubtful of the potential of methanol in the UK, on the basis of **safety concerns** and need for **new HGVs engine development** (HGVs are target vehicles for methanol in the UK)
- Furthermore, **the air quality benefits and CO_2 benefits are not unclear**
- If used for UK transport, high blend **methanol will likely be bunkered** (not at forecourts)
- UK would need to **develop codes of practise for storage and handling** of methanol as well as planning guidance; input from industry players and countries familiar with methanol will be valuable

Liquid Air (LAIR)

- Existing liquid nitrogen (LIN) production will be used first, before dedicated liquid air production is started
- LIN/LAIR will be used mostly for cooling and/or for hybrid applications, as opposed to becoming a prime mover
- It is expected LAIR will be used **exclusively by fleets with depot refuelling**
- Specialist **skilled workers will be needed** for liquid air distribution (e.g. cryogenic engineers and technicians)
- Skill-set overlap with other sectors must be investigated and consistent training programmes developed as required
- Production of LIN / LAIR require electricity but the energy vector can also be used as a form of energy storage

E85

- Consulted industry stakeholders are doubtful of the potential of E85, on the basis of the **lack of vehicle supply**, **barriers to adoption of new grade at inland terminals and forecourts** and **low energy content** (adding issue to consumer acceptance and fuel duty issue if price parity with E5/E10 (per km) must be supported)
- **Adoption of E85 could not be possible if E20 is adopted** (limit to number of grades)
- Distribution would be as for E10: blended at inland terminals and transported by trucks to forecourts

Source: Element Energy and industry input

Contents

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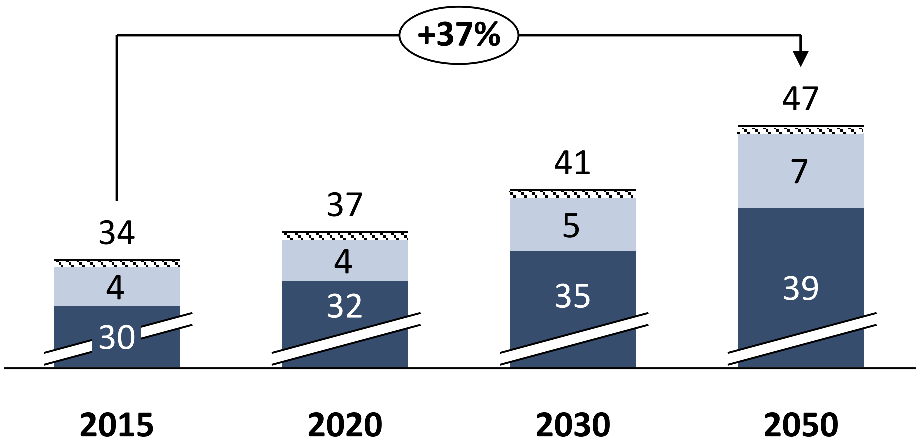
Acronyms

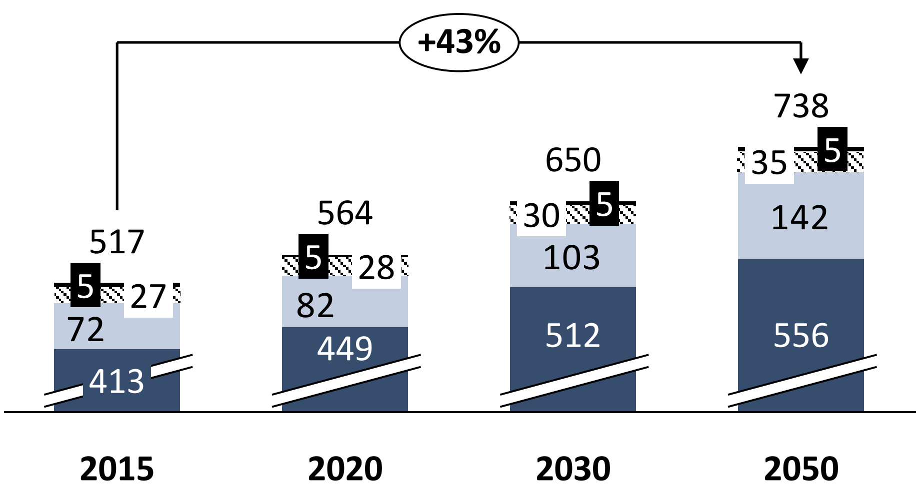
AFV	Alternative Fuel Vehicle
ASU	Air Separation Unit
BtL	Biomass-to-Liquids
CCC	Committee on Climate Change
CHP	Combined Heat and Power
COMAH	Control of Major Accident Hazard
DECC	Department of Energy & Climate Change
DfT	Department for Transport
DUKES	Digest of United Kingdom Energy Statistics
EC	European Commission
EE	Element Energy
ETBE	Ethyl Tertiary Butyl Ether
ETI	Energy Technologies Institute
EU	European Union
FAME	Fatty Acid Methyl Esters
FLT	Fork Lift Truck
HGV	Heavy Goods Vehicle
HSE	Health and Safety Executive
ICE	Internal Combustion Engine
LCN	Low Carbon Network
LIN	Liquid Nitrogen
LPG	Liquefied Petroleum Gas
MTBE	Methyl tert-butyl ether
Mt	Million tonnes
NG	National Grid
OEM	Original Equipment Manufacturer
OLEV	Office for Low Emission Vehicles
PM	Particulate Matter
R&D	Research and Development
RED	Renewable Energy Directive
RTFO	Renewable Transport Fuel Obligation
TEN-T	Trans-European Transport Networks
TRU	Transport Refrigeration Unit
TSB	Technology Strategy Board
TTW	Tank-to-Wheel
UCO	Used Cooking Oil
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	▪ ICE: petrol, diesel, LPG, (gas), (H_2 in early years) ▪ EVs: Battery EVs, plug-in hybrid EVs, fuel cell (FCEVs)	▪ ICE: diesel, (bio)methane ▪ EVs: BEV, PH/RE, FCEV ▪ (Liquid air for cooling/hybrid power)	▪ ICE: diesel, (bio)methane, (methanol) ▪ EVs - in lighter segments only	▪ ICE: diesel, LPG, (gas), Liquid air for refrigeration units ▪ (Batteries and Fuel Cells – in some applications)
KEY SOURCES / INDICATORS	▪ The Carbon Plan and the Committee on Climate Change's recommendations ▪ H_2Mobility Phase 1 report, 2013 ▪ Historic trends for petrol/diesel split	▪ Current and announced commercial availability, policy drivers ▪ *Alternative Powertrain for Urban buses*, 2012 ▪ CCC – 4th Carbon Budget Review	▪ Current and announced commercial availability ▪ DfT HGV Task Force ▪ TSB-DfT Low Carbon Truck Trial ▪ CCC – 4th Carbon Budget Review	▪ *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

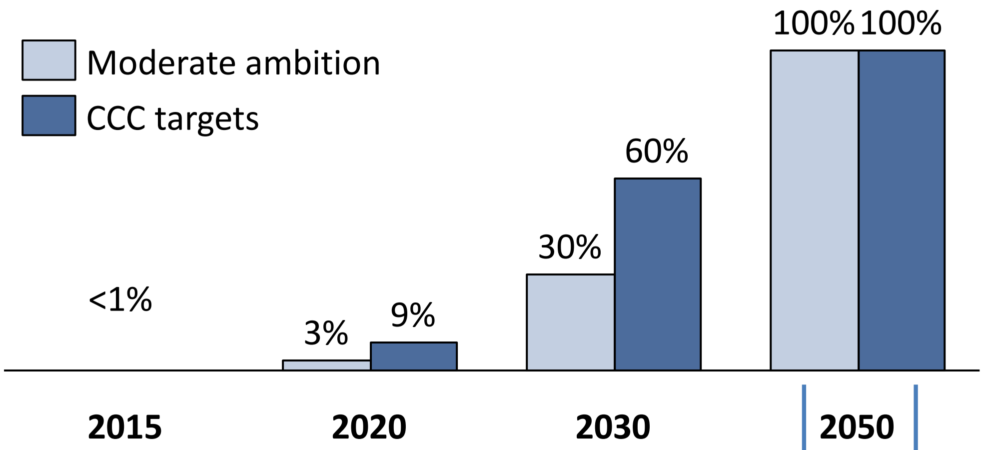
Cars and vans are expected to transition to zero emission powertrains for the UK to meet its GHG reduction targets

- 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).

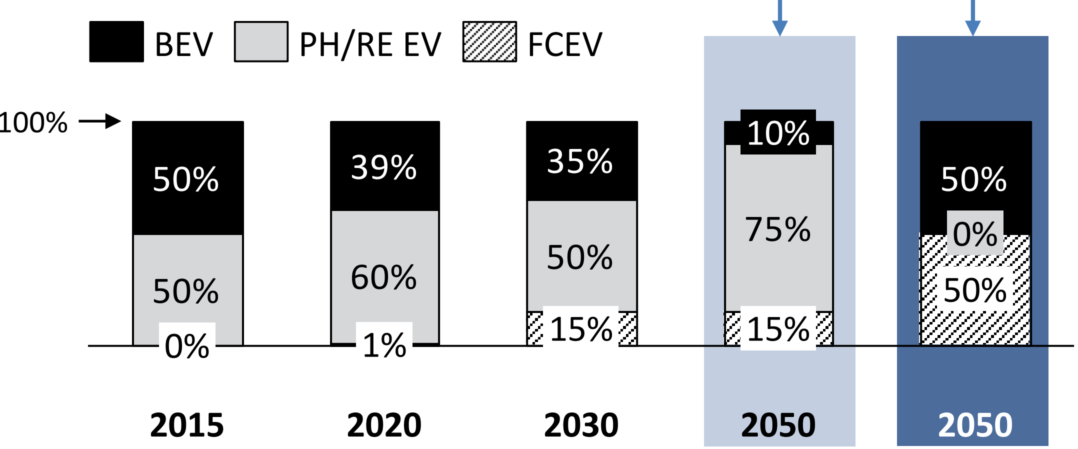
Source: Element Energy

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



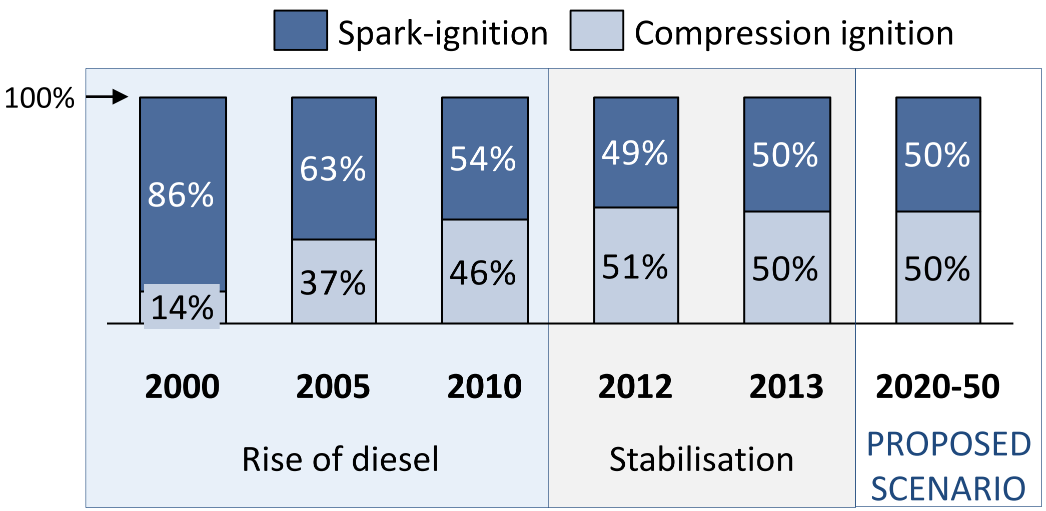
Scenarios

- 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

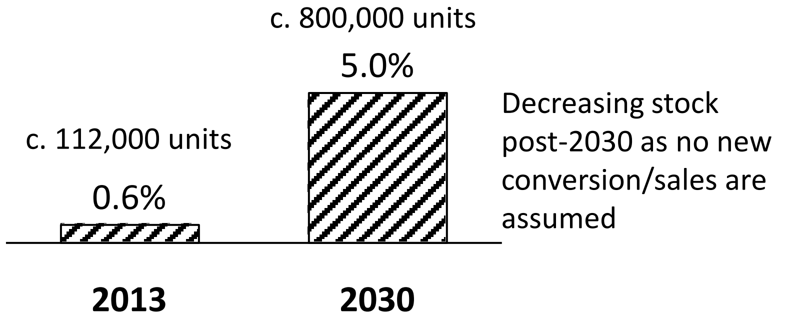
Sources: Element Energy, UK H_2Mobility report Phase 1 (2013), *Pathways to high penetration of EVs*, EE for the CCC (2013), *Options and recommendations to meet the RED transport target*, EE for LowCVP (2014)

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

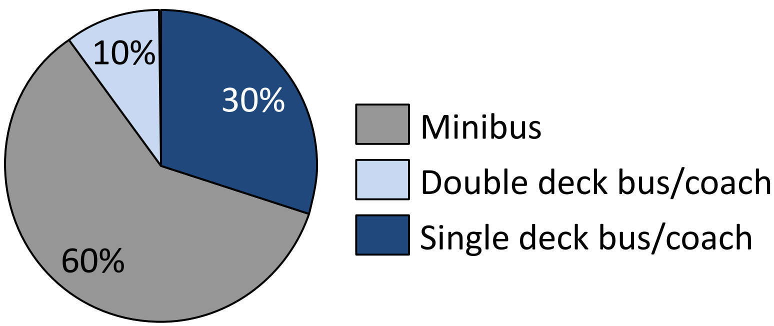
- We assumed that the current split of petrol/diesel engines for new cars (50/50) is maintained going forward
- In line with the Fuels Roadmap, diesel will be B7 (EN590) with an increasing amount of drop-in renewable diesel – i.e. no compatibility issue to be considered for the distribution infrastructure
- 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

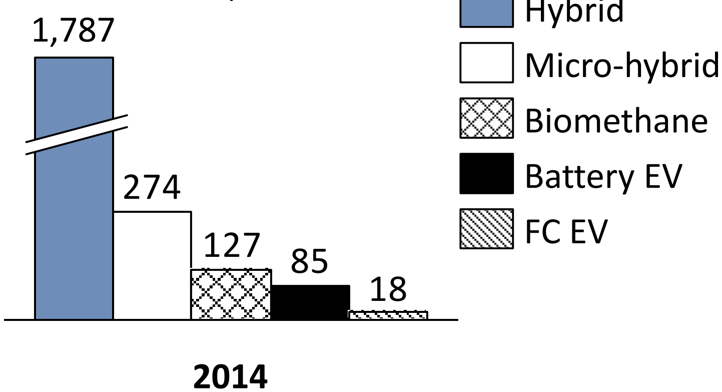
UK bus fleet, c. 165,000 vehicles:



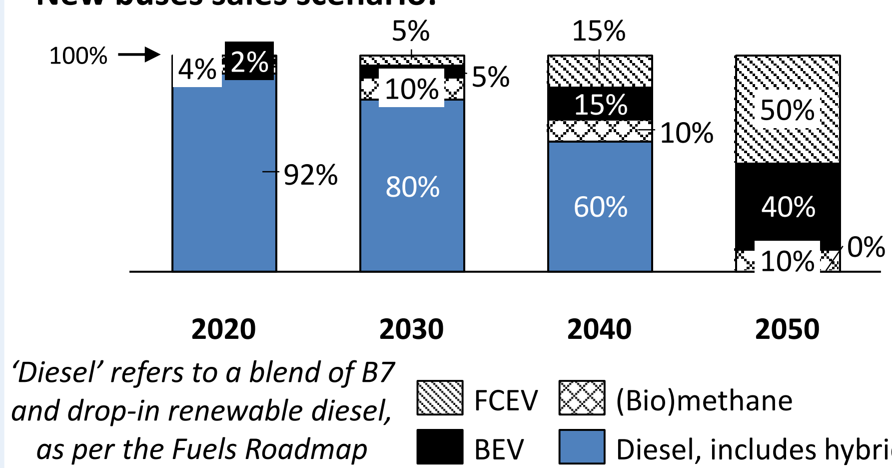
Scenario

- 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)



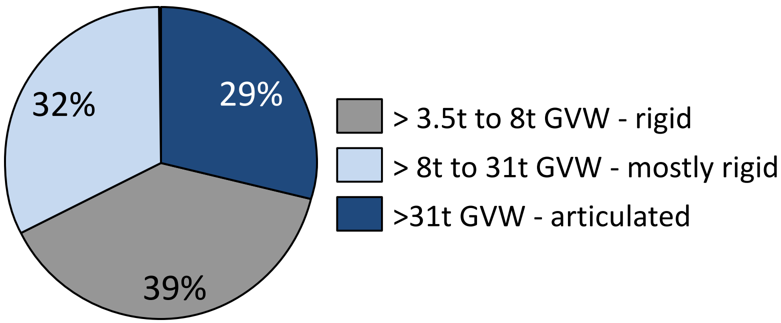
New buses sales scenario:



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

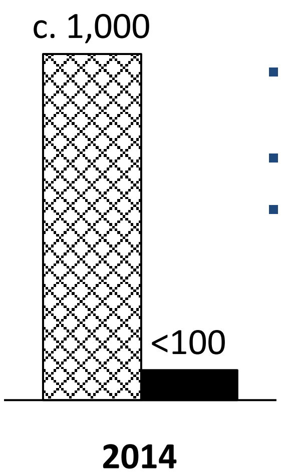
UK HGV fleet, c. 460,000 vehicles:



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

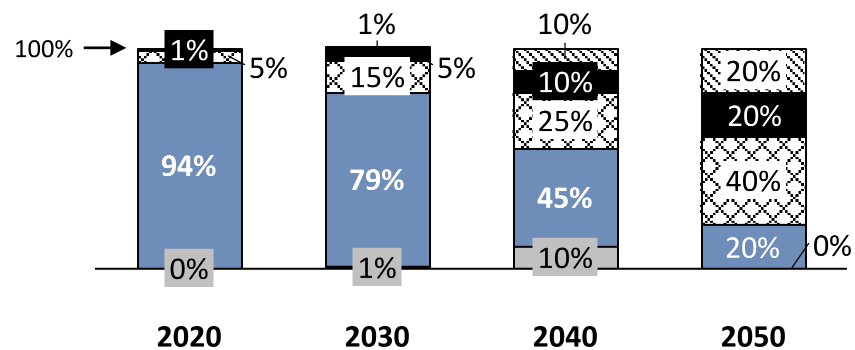


- *Gas trucks all over 18t GVW, mostly dual fuel (diesel and methane)*
- *Electric trucks all under 18t GVW*
- *FCEV light trucks at early demo stage*

Methane

Battery EV

New truck sales scenario:

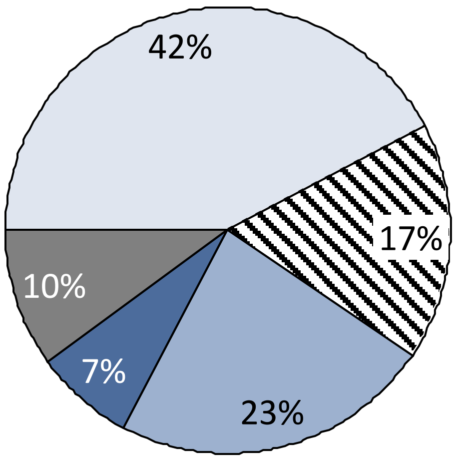


'Diesel' refers to a blend of B7 and drop-in renewable diesel, as per the Fuels Roadmap

FCEV | BEV | Methane | Diesel, includes hybrid | Diesel LPG dual fuel

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

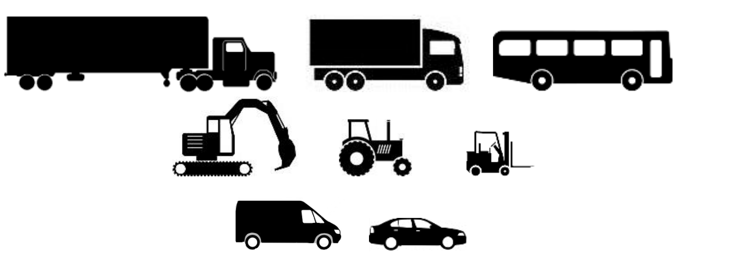
Other off-roads: Telescopic Handlers, Backhoe Loaders, Excavators, Cranes, Bulldozers, Compressors etc.

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)