The role of biofuels beyond 2020

Study commissioned by BP Biofuels

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This study uses data derived from independent and publicly available sources and represents independent work performed by Element Energy. Modelling assumptions and other aspects of the analysis do not necessarily reflect the entirety of BP's views.

This study explored the potential role and cost effectiveness of using biofuels to decarbonise UK road transport

CONTEXT

- Current GB car stock is dominated by ICE and derived powertrains - stock turnover suggests **strong role in near to mid term for ICE vehicles**
- Plug-in and other ultra low emission vehicles are expected to play a critical role in meeting long term CO_2 goals, though **deployment is likely to be gradual in the short term**
- Advanced biofuels could therefore be a cost effective route **to decarbonising the whole vehicle parc** and complement the growth of plug-in vehicles

KEY QUESTIONS

- What are the **potential emissions savings** from a realistic penetration of biofuels considering supply constraints?
- What cost does this add to the energy system? What is the **cost effectiveness of CO_2 reduction** of biofuel pathways?
- How do biofuels compare with a **more aggressive rollout of plug-in vehicles (PHEV, RE-EV, BEV)** in terms of costs of emissions savings?

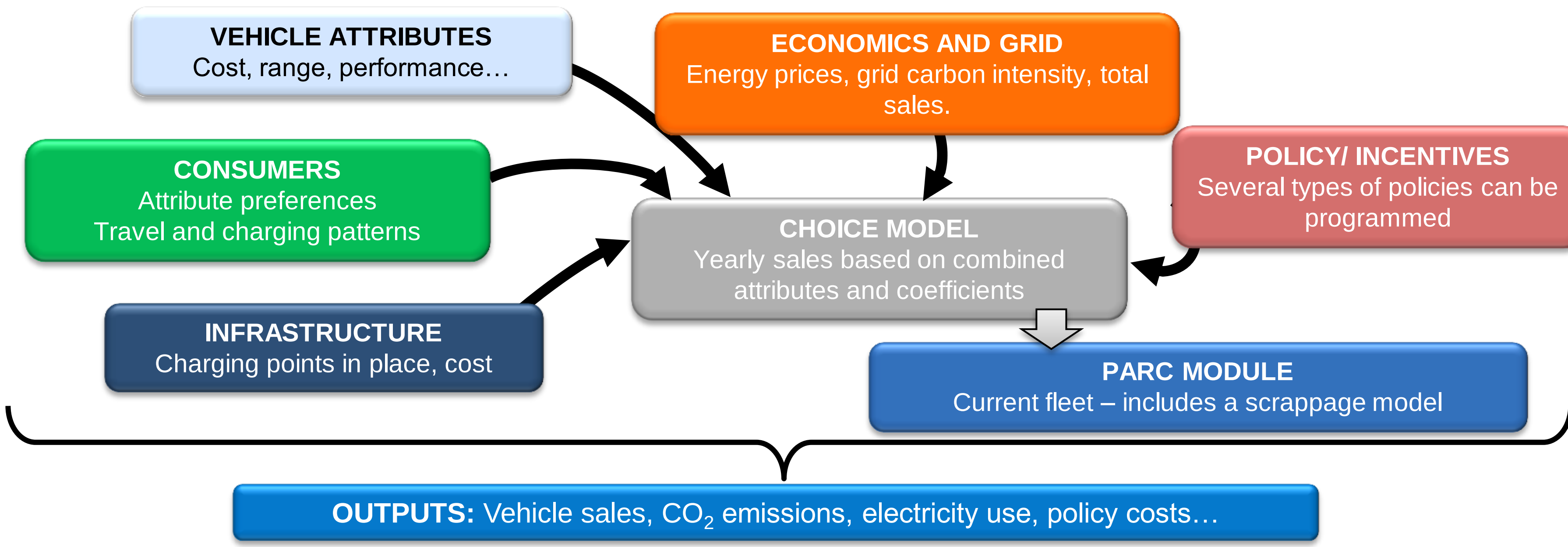
BEV: Battery Electric Vehicle; PHEV: Plug-in Hybrid EV; RE-EV: Range Extended EV

Agenda

- **Introduction: modelling methodology and biofuel pathways**
- Results
- Conclusions

Results presented today are based on the ECCo2 choice model originally developed for the ETI and DfT

Overview of ECCo2 (Electric Car Consumer Model)



- ECCo is a consumer choice model developed for ETI in 2010-11, extended and updated for DfT in 2012
- It includes cost performance data for wide range of powertrains and fuels
- Uses consumer preference data from a survey of 2,700 UK new car buyers
- Model has been updated to include improved data on biofuel performance and supply
- Core assumptions consistent with model in use by DfT

Key inputs and outputs overview given in Appendix

The representation of biofuels in the model has been enhanced using improved data on fuels performance and costs

Previous biofuel inputs

- Fixed **5% blend of biofuels** to 2030
- Biofuels based on 100% **conventional ethanol** while biodiesel is made of **FAME, HVO and BTL diesel**
- **No change in WTW performance** of biofuels over time (69% and 40% for ethanol and biodiesel respectively)

Updates in this study

- **3 new pathways developed** to represent a range of possible biofuels futures
- **Contributions of different fuels / feedstocks evolves over time** in-line with fuel availability and performance
- **Production costs for each fuel** included from publicly available sources
- **WTW emissions improve over time** reflecting these changing fuels / feedstocks
- **Supply constraints are included**, consistent with DECC estimates of sustainable biofuel volumes and IEA estimates of advanced biofuel availability

The three new biofuel pathways represent differing levels of biofuel availability and biofuel type

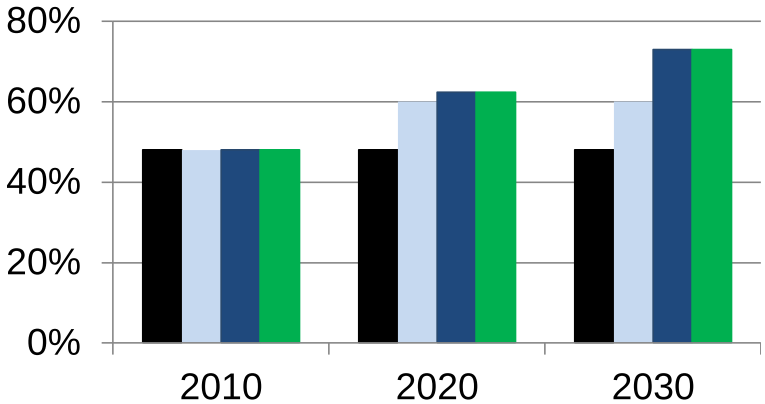
Name	Pathway	Gasoline blend[1]	Diesel blend
BASELINE	No increase in blending; biofuels based mainly on conventional biofuels and no improvement in GHG emissions savings over time	E5	5% by volume – FAME in 2010, moving to HVO and BTL in 2030
LOW BIOFUELS	Slightly higher blend, still relying on conventional biofuels, based on observed savings (recent RTFO reports) with improvement over time	E10 from 2015	Increase to 7% from 2015, mix as above
MEDIUM BIOFUELS	Incremental introduction of higher ethanol blend from 2020, moving to 50% cellulosic ethanol by 2030, within supply constraint as identified by IEA	E20 from 2020	7%, mix as above
HIGH BIOFUELS	‘Stretch’ case with significant role for ethanol, butanol and drop-in fuels. Matches the light vehicle biofuels medium supply potential identified in DECC bioenergy strategy	Bu15 from 2020, Bu24 from 2025 and up to 19% drop-in gasoline by 2030	7% from mix as above, plus increasing BTL post 2019, giving 19% drop-in diesel by 2030

Also supplied in biofuel pathways: E85 (capped at 10% of total gasoline MJ)

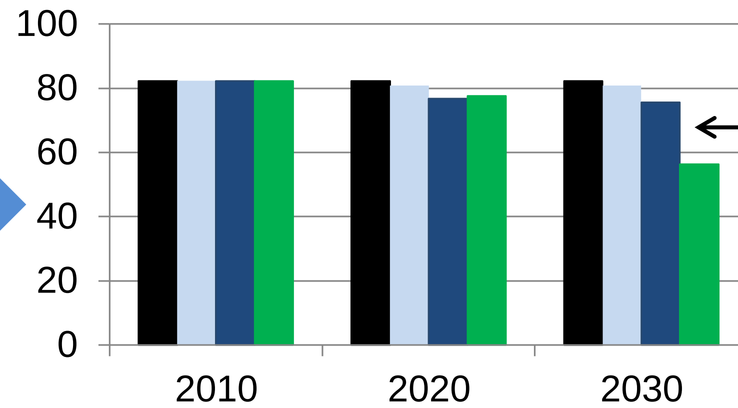
1 - Stock non-compatibility with new blends is accounted for in the model; see Appendix p31-32

In all biofuel pathways, gasoline and diesel show a decrease in WTW emissions due to higher blends and increase in biofuel WTW savings

Ethanol & butanol WTW savings (relative to gasoline)



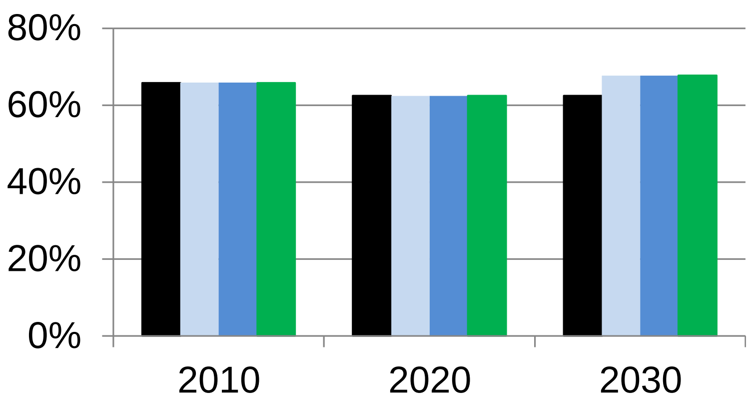
Gasoline blend WTW emissions (gCO_2e/MJ)



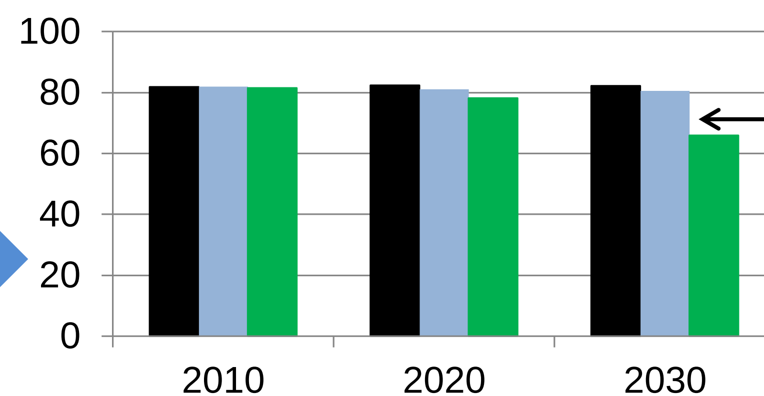
8% lower WTW emissions relative to BASELINE

■ BASELINE ■ LOW BIOFUELS ■ MEDIUM BIOFUELS ■ HIGH BIOFUELS

Biodiesel WTW savings (relative to diesel)



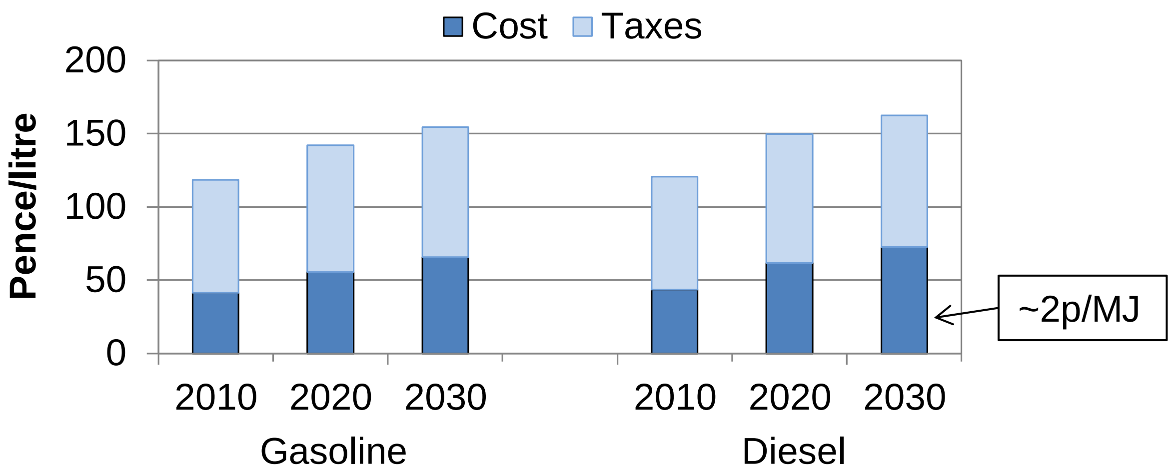
Diesel blend WTW emissions (gCO_2e/MJ)



2% lower WTW emissions relative to BASELINE

Costs of supplying biofuels are accounted for through a premium spread over all liquid fuels

Price of fuels in ECCo (2010 prices) – baseline price before addition of biofuel cost premium



Biofuel cost, p/MJ – kept constant to 2030

Fuel	p/MJ	Source
Conventional ethanol and butanol	2.335	Ethanol 5 year average Jan 2008 - Jan 2013 FOB Rotterdam (Platts)
FAME and HVO	1.945	FAME 5 year average Jan 2008 - Jan 2013 FOB Rotterdam (Platts)
FT diesel and drop in gasoline	1.945	BP/EPC contractor Wood to wheels study
Cellulosic ethanol	1.795	NREL, May 2011

Overview of fuel cost inputs

- Fuel prices as per 2012 DECC projections
- Cost premium of biofuels:
  - Calculated from biofuels costs (table)
  - Spread over both gasoline and diesel supply, based on previous year's use
  - Added to gasoline and diesel price
- This ensures the cost of RTFO compliance is represented in the overall system cost

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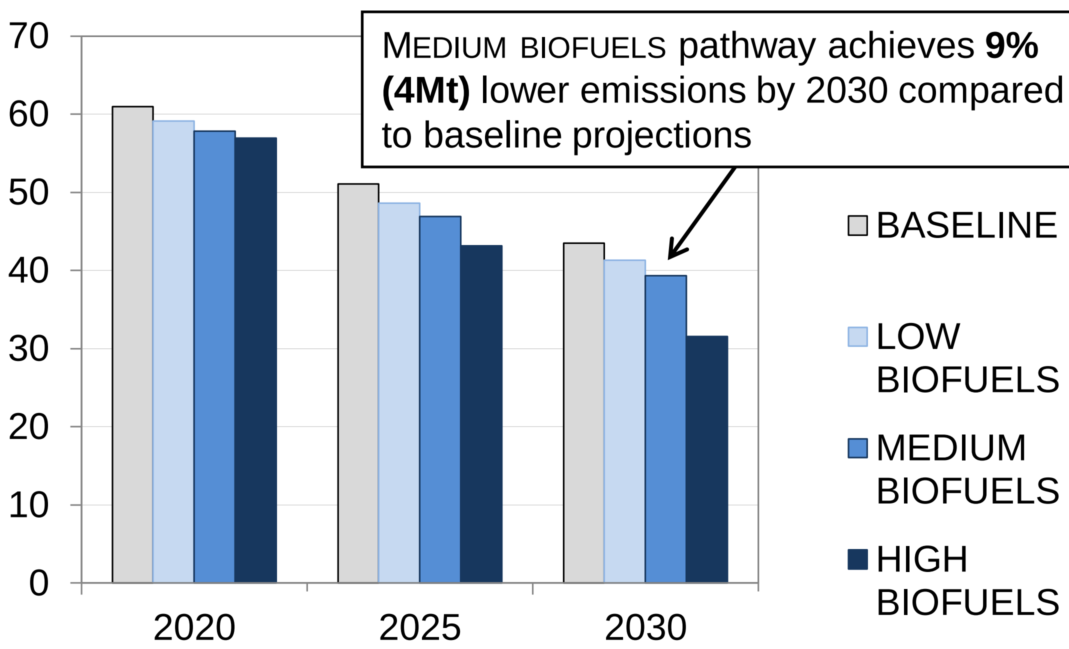
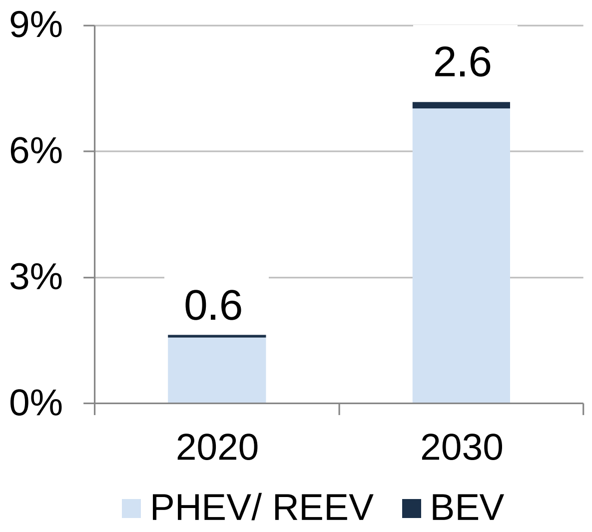
- Introduction: modelling methodology and biofuel pathways
- Results:
  - **Biofuels deliver large emissions savings at low cost premium**
  - Biofuels offer more cost effective CO_2 savings for vehicle users
  - The system costs for the UK of delivering emissions savings with biofuels is lower than with plug-in vehicles
- Conclusions

Biofuels provide strong decarbonisation potential due to high numbers of ICE-derived vehicles still in circulation by 2030

WTW emissions, Mt CO_2e – includes electricity production



Share of plug-in vehicles in parc (%) and number in the fleet (million)

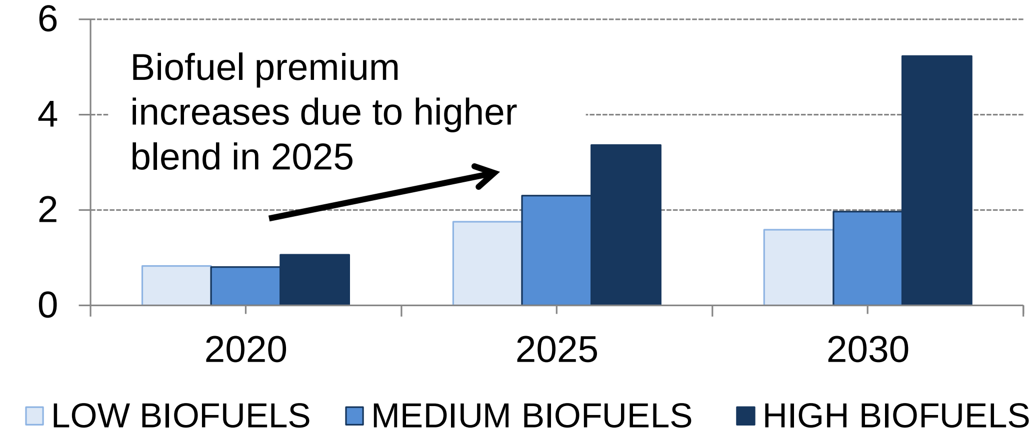


Key insights

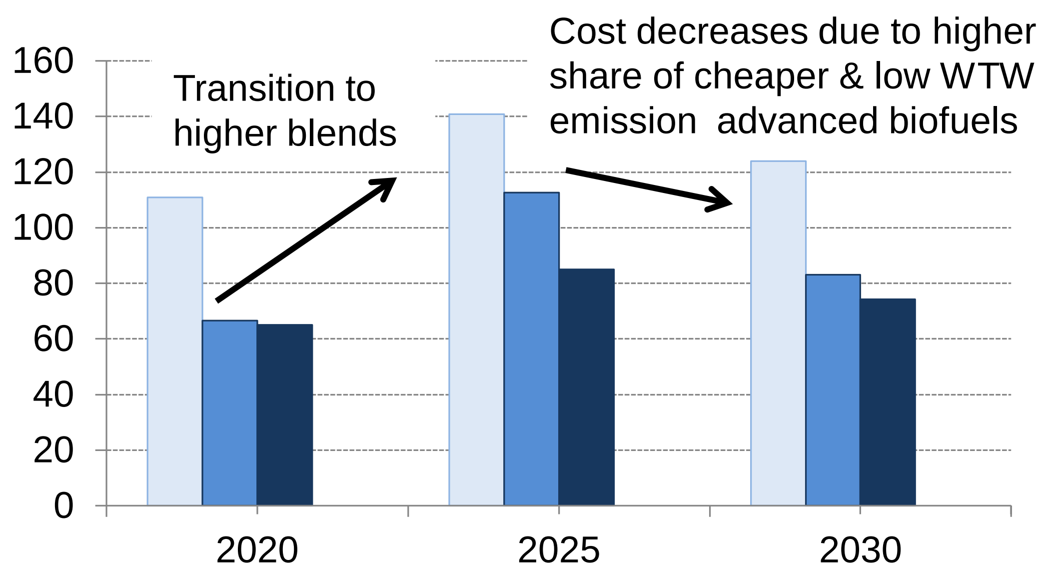
- In all biofuel pathways, as in the base case, plug-in vehicles capture 11% of market share, amounting to over 340,000 annual sales and 2.6 million on the road by 2030
- However more than 90% of stock is ICE / HEV and most plug-in vehicles are PHEVs, resulting in a high reliance on liquid fuel of 520 PJ (98% of energy use)
- With a high deployment of biofuels, emissions are reduced for majority of the car parc

Achieving this 4Mt GHG emission savings with biofuels add only £13 per year to fuel spending

Annual biofuel premium cost (p/l)



Annual cost effectiveness of emission reduction (£/tCO_2)



Calculation of cost effectiveness

- The overall cost effectiveness of a scenario in reducing emissions is calculated as the annual cost of emission savings (£/tCO_2):
  - The annual savings (Mt) and additional cost (£m) are calculated relative to the BASELINE pathway
  - The additional cost is calculated as additional cost for supply of biofuels and E85 stations

Key insights

- In MEDIUM and HIGH pathways, the increase in lower carbon advanced biofuels leads to cheaper and better emission savings than in the LOW pathway
- Achieving 4Mt emission savings add only £13 to annual fuel spending in average (2 pence per litre premium on fuel cost at the pump) in the MEDIUM pathway

Emission savings based on WTW CO_2e i.e. TTW emissions + fuel and electricity production

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  - The system costs for the UK of delivering emissions savings with biofuels is lower than with plug-in vehicles
- Conclusions

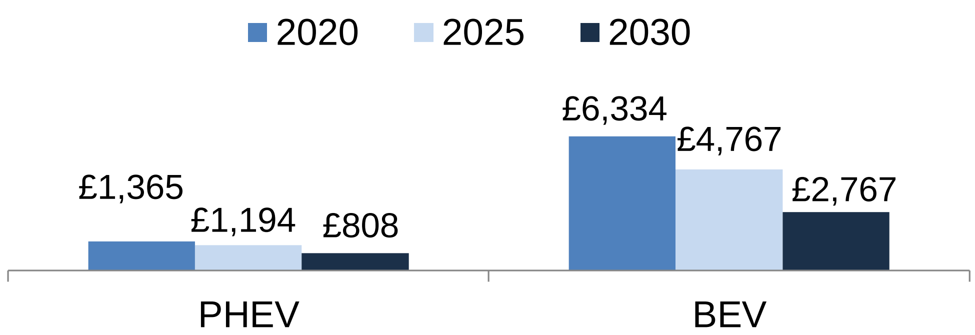
Battery electric vehicles deliver strong CO_2 savings with a decarbonised grid, but are expected to have significantly higher costs than ICE and HEV cars to 2030

COST OF VEHICLES TO DRIVERS (£) AND COST EFFECTIVENESS (£/tCO_2)

Cost and emission comparison relative to HEV using 5% blend in 2030 with vehicles in MEDIUM BIOFUELS pathway[1]

BEV	HEV
Extra capex £6,200	**No extra capex**
Annual fuel savings £425	Annual biofuel premium £13
Annualised cost £195	Annualised cost £13
WTW savings 89%	WTW savings 10%

4 year TCO premium over gasoline HEV model[2], £



Overview of cost comparison

- Capex of BEV is higher than HEV by £6,200 in 2030 but can provide high WTW savings with a decarbonised grid
- These vehicles remain significantly more expensive than HEV and PHEV on a Total Cost of Ownership (TCO) basis, hence uptake in the model is low even in 2030
- Biofuels rely on conventional powertrain and hence have zero additional capital costs - only added costs are the fuel cost premium

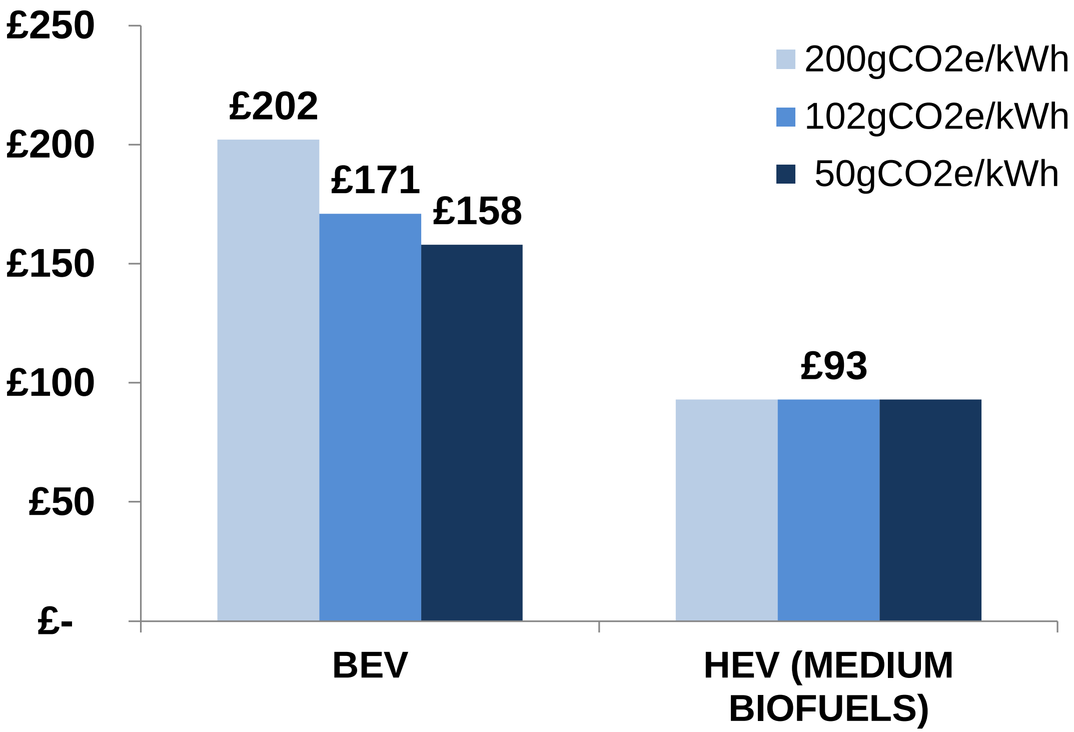
Grid assumption: by 2030 grid electricity carbon intensity down to 102gCO_2/kWh (based on 2012 DECC projections)
Vehicle costs and MJ/km based on Ricardo-AEA modelling for the Committee on Climate Change (2012)

1 - 10 year lifetime, energy prices of £1.6/l and 20p/kWh in 2030. No discounting
2 - TCO premium based on capex, energy cost (kept constant over 4 years), 13,800 km p.a. No discounting

Biofuels have lower cost of emissions savings for the consumer than BEVs even with decarbonised grid

Based on calculations presented in the previous slide

Annualised cost of emission savings in 2030, segment C car, for various grid intensities, £/tCO_2,[1]



Grid assumption for 2030:

102gCO_2/kWh : DECC central projections (2012)

50gCO_2/kWh and 200gCO_2/kWh: sensitivities used in DECC analysis

Key insights

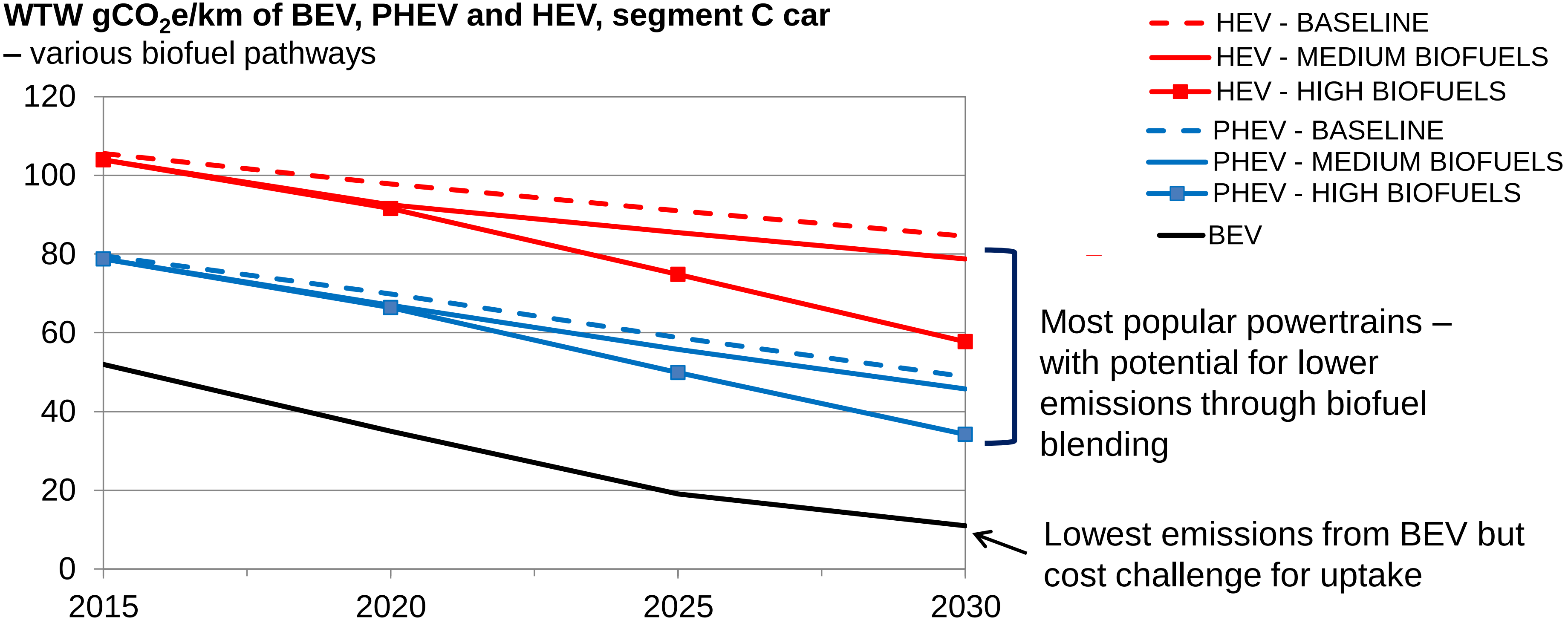
- BEVs show a high cost of reduction despite highly decarbonised grid, due to significant capital cost premium even in 2030
- Annual cost of emissions reduction for BEVs in 2030 is **£160** to **£170/tCO_2**
- Under the MEDIUM BIOFUELS pathway, an HEV (running with E20) offers WTW emissions reduction at a **40%** lower cost than BEV

1 - Includes extra capex (annualised over 10 years), fuel savings and biofuel premium

Biofuel pathways are complementary to HEVs and PHEVs, the most popular powertrains post-2020

MODEL INPUTS ON VEHICLE WTW EMISSIONS (gCO_2/km)

WTW gCO_2e/km of BEV, PHEV and HEV, segment C car – various biofuel pathways



Key insights

- Biofuels provide potential to lower emissions of PHEVs (and HEVs), and hence are complementary to efforts to electrify transport in the medium term
- Biofuels, PHEVs and HEVs could provide a transition to a future high BEV scenario, when technology cost reduction makes them cost competitive these powertrains

Note: graph shows HEV and PHEV data for gasoline models

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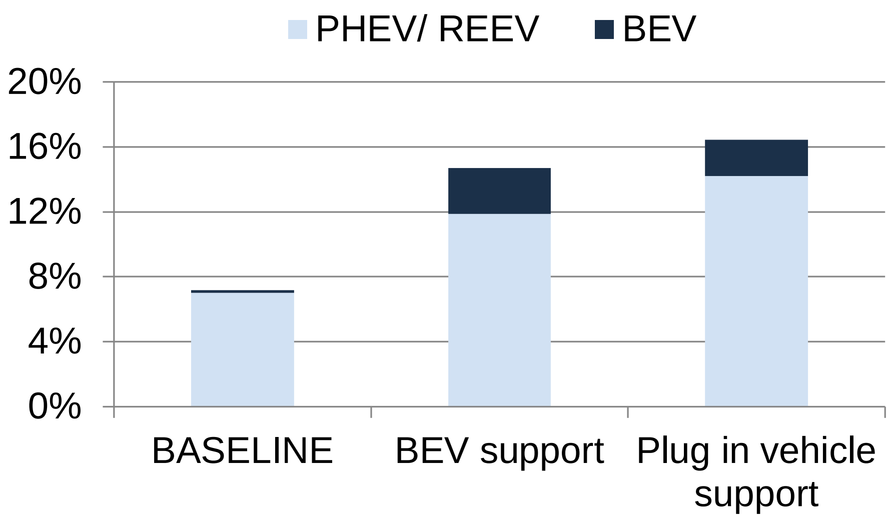
- Conclusions

A high plug-in vehicle case was modelled by relaxing customer constraints and applying strong vehicle price reductions

Share of plug-in vehicles in GB fleet in 2030, %



Consumers see a price reduction for BEVs in 2015-22

Consumers see a price reduction for all plug in vehicles in 2015-2022

+

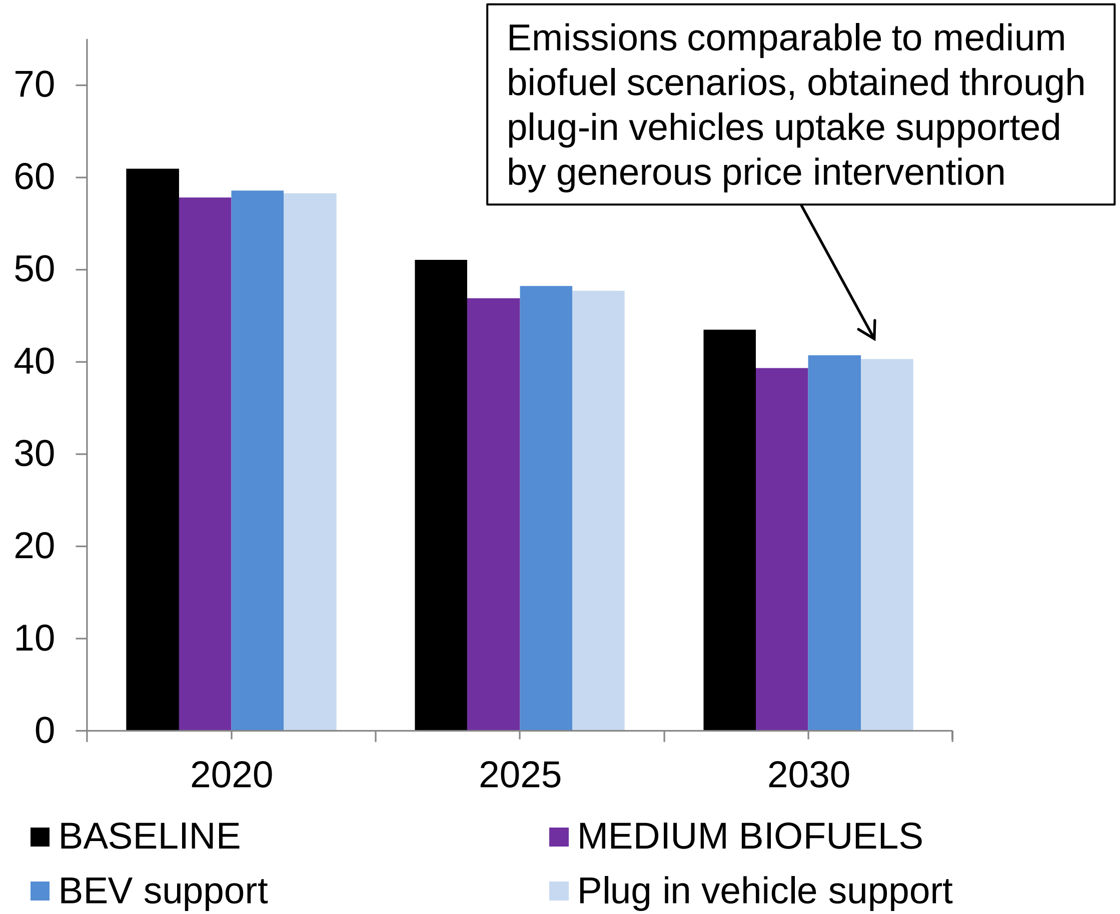
Consumers make choice based on TCO only, i.e. no technology preferences nor penalty for range/infrastructure limitations

Description of high plug-in vehicle case

- In the baseline run, the uptake of plug-in vehicles is low, BEV in particular, because of their cost premium as well as consumers' preferences in terms of range, technology and infrastructure access
- Two scenarios were modelled where consumers choose vehicles only on the basis of total costs of ownership, i.e. ignoring range/infrastructure limitations
- In addition consumers see generous price reductions (e.g. through subsidy or discounting) beyond the cost reductions through technology improvements
- The large number of PHEV/REEV in these scenarios would continue to benefit from decarbonised liquid fuels

Generous price intervention is needed to get high penetration of plug-in vehicles to provide similar emissions savings to medium biofuels scenario

WTW emissions, Mt CO_2e – includes electricity production



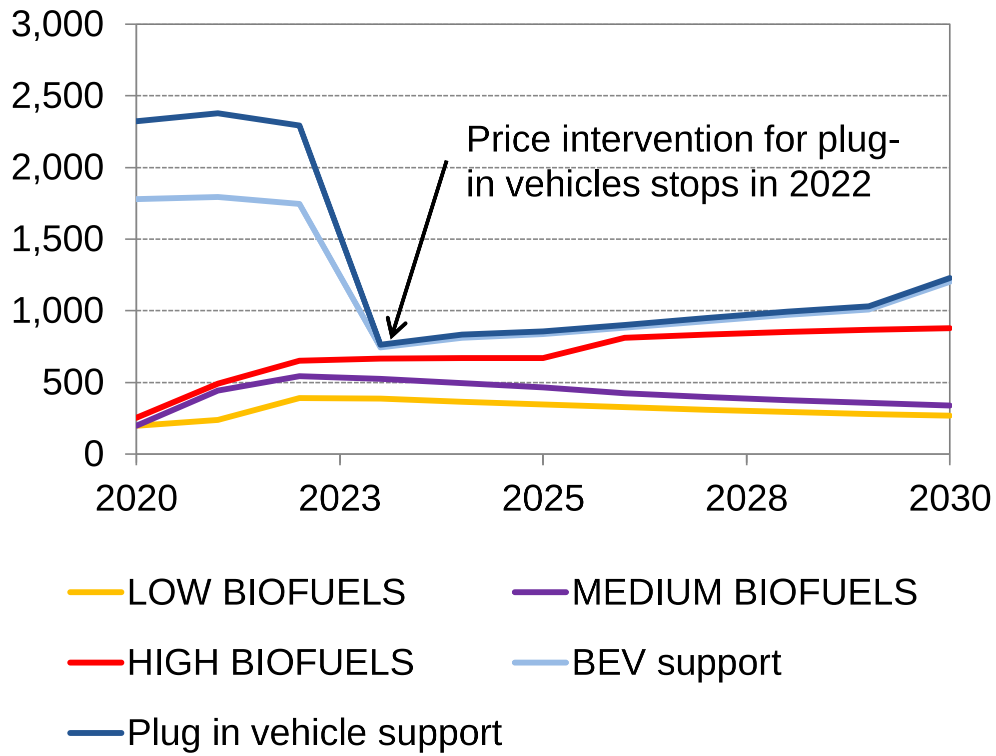
Key insights

- An additional price reduction for plug-in vehicles of £5,000 until 2022 was required to deliver similar CO_2 savings to the MEDIUM BIOFUELS pathway
- It suggests that significant price interventions (either incentives or manufacturer cross-subsidy) over ~10 years are required to increase plug-in vehicle uptake beyond the baseline level

BEV SUPPORT and PLUG IN VEHICLE SUPPORT scenarios use the same biofuel pathway than BASELINE scenario, i.e. E5 and B5 blends

Achieving savings through high plug-in vehicle uptake results in a 3 times higher cost compared with fuel premium in biofuel pathways in 2030

Additional cost to the UK, £m



Additional costs:

- Biofuel pathways: supply of biofuels (fuel premium)
- Support scenarios: plug-in vehicles sales (accounting for fuel cost savings)

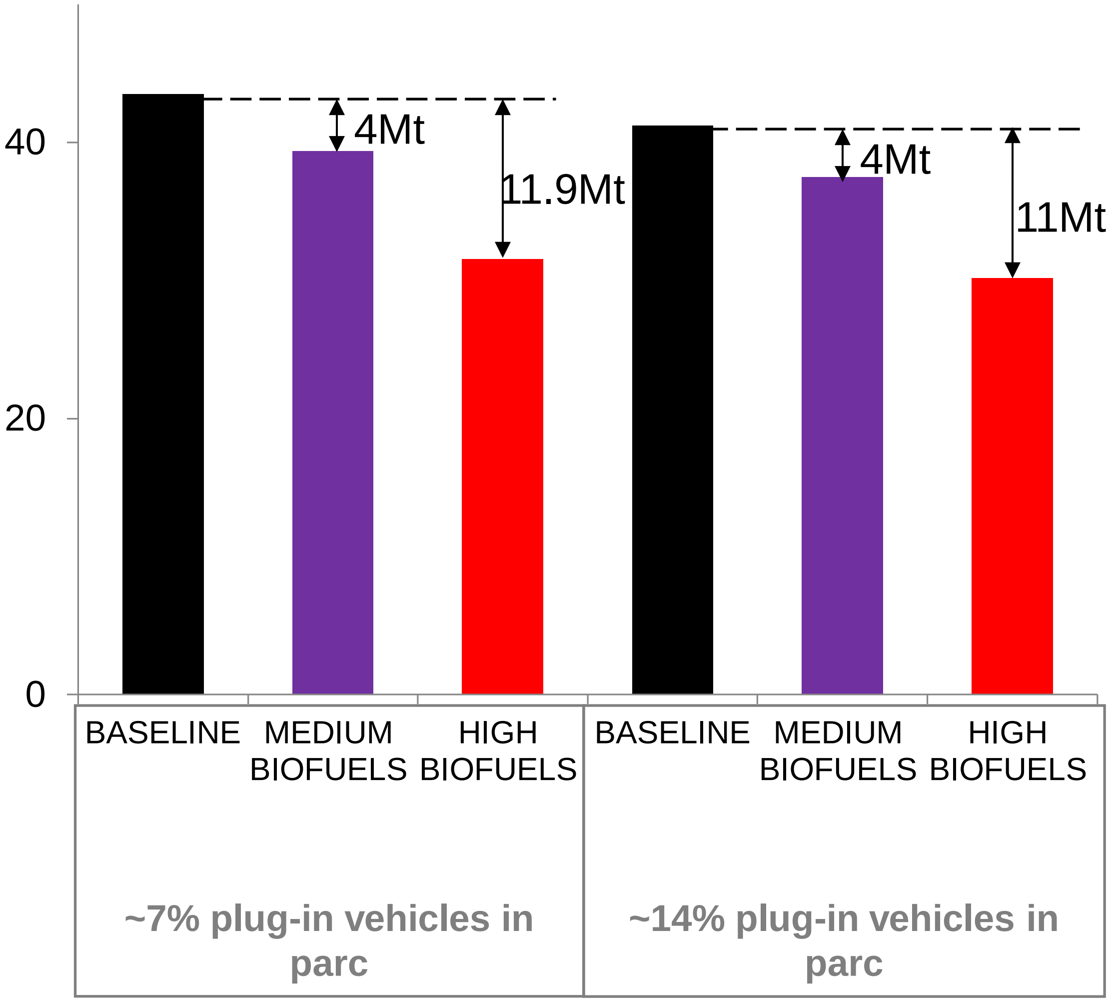
Key insights

- Cost premium in biofuel pathways arises from the blending of ethanol, butanol, biodiesel and drop-in fuels that are more expensive than conventional gasoline and diesel
- Premium cost of MEDIUM BIOFUELS pathway reaches **£336m** in 2030 for WTW savings of **4.1Mt/y**
- The comparative added cost of plug-in vehicles is around **£1,230m** by 2030 for WTW savings of **3.15Mt/y**, i.e. 3 times the cost of the MEDIUM BIOFUELS pathway
- Cost effectiveness of MEDIUM BIOFUELS pathway is over 4 times better: **£82/tCO_2 vs. £390/tCO_2**
- For the HIGH BIOFUELS, 2030 figures are **£880m** and **11.9Mt/y**, giving a cost effectiveness of **£74/tCO_2**

Additional costs in graphs are calculated against BASELINE scenario. WTW savings achieved in 2030: LOW BIOFUELS 2.1 Mt; MEDIUM BIOFUELS 4.1Mt; HIGH BIOFUELS 11.9Mt; support scenarios 2.8Mt (BEV) to 3.15Mt

In addition, biofuels reduce risk by delivering similar CO_2 savings independent of the uptake of plug-in vehicles

2030 WTW emissions, Mt CO_2e – includes electricity production



Key insights

- Relying exclusively on ultra-low emission vehicle technologies for long term emission reduction introduces a risk of not meeting targets as uptake might be lower than expected due to cost and consumer acceptance
- By reducing emissions from all ICE vehicles, advanced biofuels could lower this risk, offering a cost-effective hedging strategy
- Advanced biofuels do not preclude the introduction of plug-in vehicles and bring advantages even if high plug-in vehicles sales are achieved in medium term

Agenda

- Introduction: modelling methodology and biofuel pathways
- Results
- **Conclusions**

Summary and conclusions

The key findings are:

1. **High level of biofuels blending can be achieved within supply constraints and achieves significant emission savings** (up to 4Mt/year in medium pathway). Advanced biofuels technologies allow this high level of blending, and reduce lifecycle GHG emissions from the biofuels mix.

2. At vehicle level, **blending biofuels in fuels is a cheaper way to reduce emissions than using BEVs**: biofuels translate into an average £13 annual cost increase for consumers compared to £170 annualised cost for BEVs. This translates into costs **of £93/tCO_2 versus £170/tCO_2.**

3. Achieving savings through high plug-in vehicles uptake results in an **additional cost to the UK of £1,230m against a fuel premium of £336m in biofuel pathways in 2030**.

4. **Biofuel pathways are complementary to HEVs and PHEVs**, which are expected to dominate low carbon powertrains during the 2020s.

5. Advanced biofuels address emissions of both new and existing vehicles, thus reducing emissions earlier than new powertrains and **abating the risk of relying solely on longer term deployment of new technology**.

Implications

- To capture the benefit of advanced biofuels, **policy signals must be in place for the supply chain to develop** and provide a major contribution to emission reductions in the 2020s.

- By supporting advanced biofuels, **the UK has the opportunity to significantly reduce the fleet emissions by 2030**, ahead of the market maturity of zero tailpipe emission vehicles.

- **Increasing the role of advanced biofuels in road transport has a low risk of technology lock-in** since the majority of vehicles, including PHEVs, benefit from biofuel blending.

For more information

- The report is available online at http://www.element-energy.co.uk/publications/
- For questions or comments, contact:

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References

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Acronyms

BEV	Battery Electric Vehicle
BTL	Biomass To Liquid
CCC	Committee on Climate Change
CO_2	Carbon Dioxide
DECC	Department of Energy and Climate Change
E85	Ethanol blend (up to 85%vol) – modelled at 75%vol to account for seasonal variations
ECCo	Electric Car Consumer model
ETI	Energy Technologies Institute
EU	European Union
EV	Electric Vehicle
FAME	Fatty Acid Methyl Ester
FCEV	Fuel Cell EV
F-T	Fischer Tropsch
HVO	Hydro treated Vegetable Oil
ICE	Internal Combustion Engine
IEA	International Energy Agency
NREL	National Renewable Research Laboratory
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid EV
PiV	Plug-in Vehicle (PHEV, RE-EV, BEV)
RED	Renewable Energy Directive
RE-EV	Range Extended EV
RTFO	Renewable Transport Fuel Obligation
TCO	Total Cost of Ownership
TTW	Tank To Wheel
UCO	Used Cooking Oil
UK	United Kingdom
UKERC	UK Energy Research Centre
VED	Vehicle Excise Duty
WTW	Well To Wheel

Appendix

ECCo - Key model inputs and outputs

KEY INPUTS

Cost and performance of powertrain technologies – updated battery costs

Consumer behaviour – quantitative survey on 2,700 new car buyers

Fuelling infrastructure cost and roll-out – charging posts, H_2 stations and E85 stations

Policy levers – EU emission targets, national policies (taxes and grants)

Fuel emissions and costs – biofuel pathways proposed by BP, fossil fuel and electricity prices based on latest projections from DECC, biofuel prices/costs from public sources *(presented in slides 6-8)*

KEY OUTPUTS

Technology uptake – sales and parc penetration

Cost to consumer – average car price and average Total Cost of Ownership (TCO)

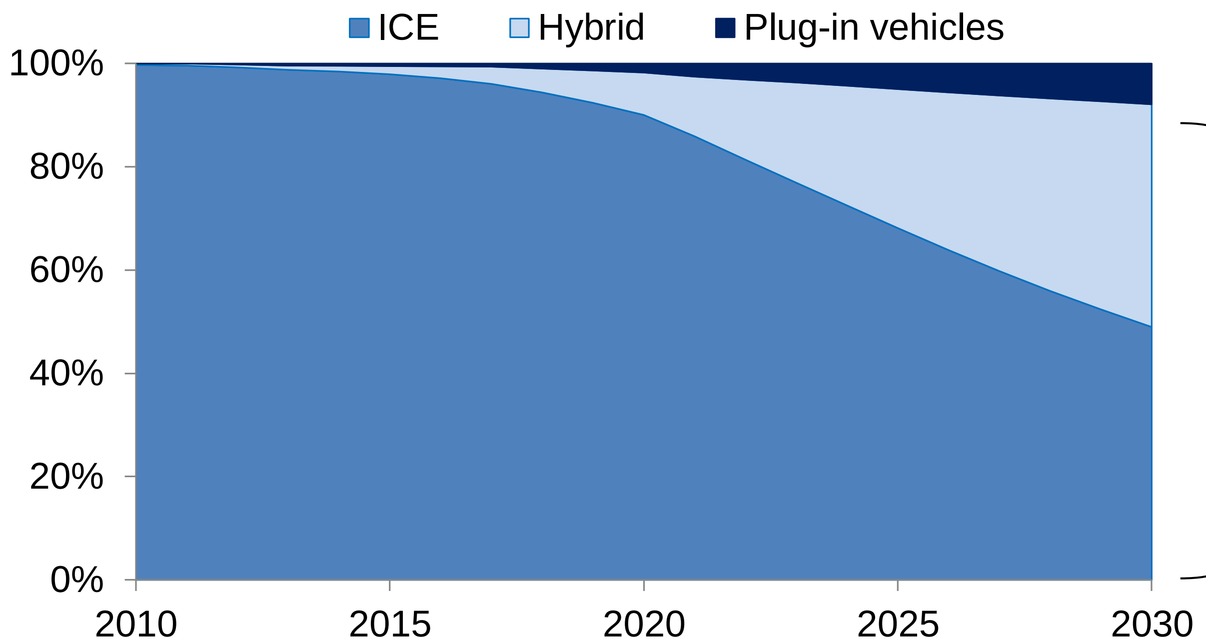
Infrastructure cost – capex and opex; charging posts, H_2 and E85 stations

Policy – government spending on incentives, GB car fleet emissions, OEM cross-subsidy of powertrains

Biofuel sales – check implied supply level, associated fuel cost premium

The ECCo base case suggests a strong role for ICE vehicles (including PHEVs) to 2030 and hence continued demand for liquid fuels

GB car stock - ECCo base case



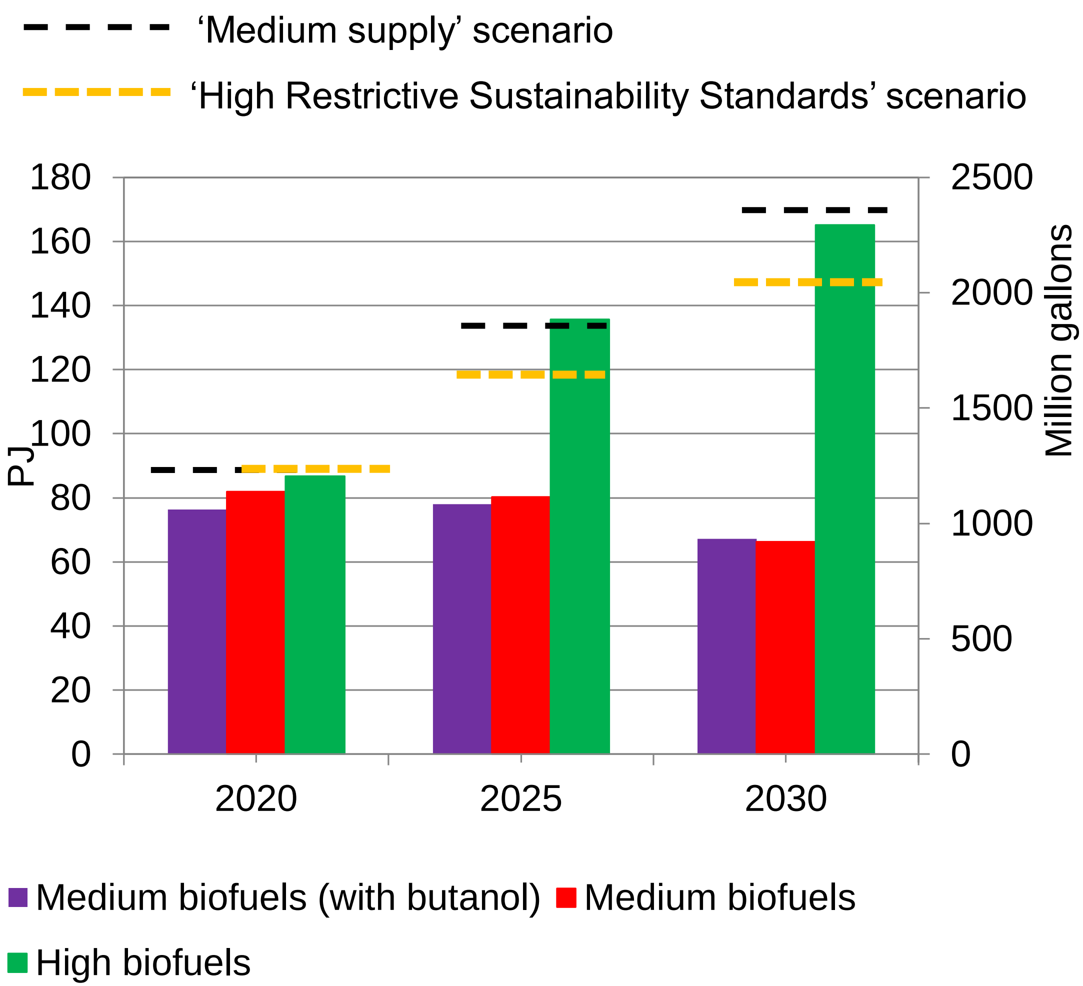
More than 90% of the stock is still ICE/Hybrid and thus reliant on liquid fuels (~98% of total 530PJ energy demand is through liquid fuels)

Baseline assumptions

- Continuing EU CO_2 legislation (42g/km in 2050) and no subsidies after 2015
- Policies based on CO_2 emissions (EU target, VED and company car tax) are based on TTW emissions
- Battery EV range increases by 50-100% by 2030
- Fuel consumption in ICE reduces (25%-40%) through mass reduction, aerodynamics etc
- EV infrastructure is deployed in businesses and public places to match vehicle ramp-up
- Biofuel content of gasoline /diesel: 5% (by volume)

Total biofuel use in all pathways is within supply constraints identified by DECC in the 2012 UK Bioenergy Strategy

Total biofuel demand and supply constraint
(ethanol, butanol, biodiesel and drop-in fuels)



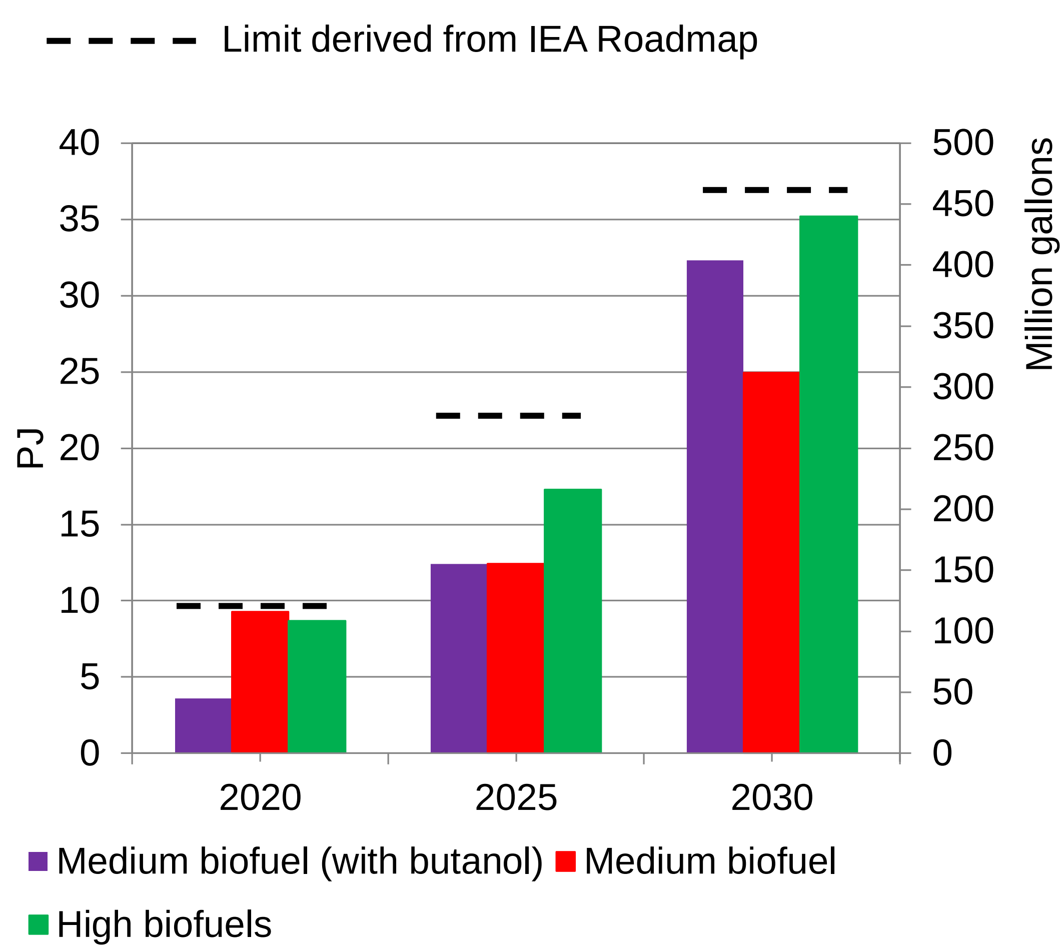
Total biofuel use

- Biofuel use is limited by DECC modelling for the Bioenergy Strategy, which gives liquid biofuel use in light vehicles under different resource scenarios.
- The medium resource scenario is used here to cap supply of the HIGH BIOFUEL pathway.
- The MEDIUM BIOFUEL pathways fall well within the 'High Restrictive Sustainability Standards'.
- Note that biofuels demand in the medium biofuels scenario decreases as overall gasoline consumption drops (improvement in vehicle fuel efficiency)

Conversion to gallons: 80.2MJ/gal

Advanced biofuel use in all pathways is within supply constraints identified by the 2011 IEA Biofuels Roadmap

Cellulosic ethanol / butanol demand and supply constraint



Cellulosic ethanol or butanol use

- Use of cellulosic ethanol or butanol is limited by cellulosic ethanol production capacity as projected in the IEA Biofuels Roadmap
- Global supply constraint on cellulosic ethanol/butanol of 460PJ in 2020 and 1840PJ in 2030. Based on UK's share of OECD gasoline, this gives 9PJ and 37 PJ for the UK.
- Demand for cellulosic ethanol /butanol increases in 2025 and 2030 as the volume share increases

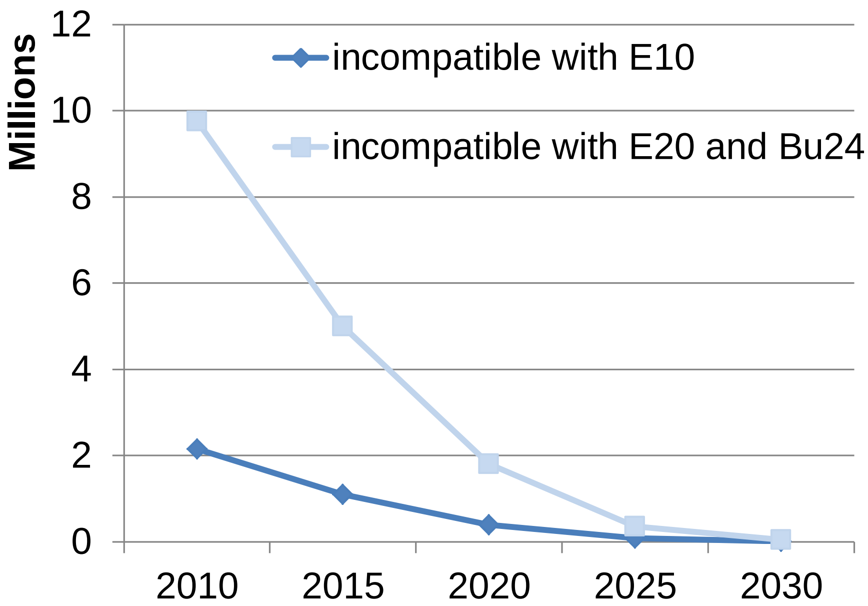
Drop-in fuels use

- Use of drop-in gasoline (37MJ) and drop-in diesel (43MJ) in 2030 in the HIGH BIOFUEL pathway falls within the potential identified by the IEA of 3,400 PJ globally (1,400 PJ biojet, 2,000 PJ advanced biodiesel).

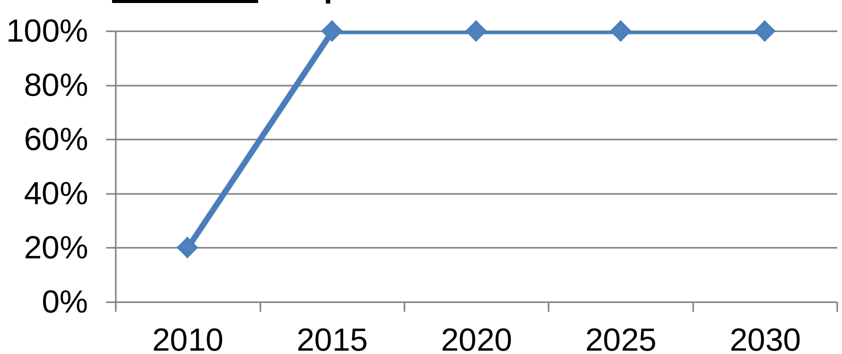
Conversion to gallons: 80.2MJ/gal

Stock non-compatibility with new blends is accounted for in the model

Number of gasoline ICE on the road from pre-2010 stock non compatible with E10 and with E15/Bu24 & E20



Share of <u>new cars</u> compatible with E15/Bu24 and E20



Stock from pre-2010 sales incompatibility

- E10: based on conservative 13% figure as identified by SMMT in 2012 (9% incompatible and 4% to be confirmed)
- E15/Bu24 and E20: based on 50% (of which 13% is already accounted above) - ***Conservative estimate***[1]
- B5/B7: assume all diesel cars compatible

Assumptions for cars sold from 2010

- E10 / Bu15: all compatible
- E15/Bu24 and E20: see bottom graph
- E85: all cars from 2020
- B5/B7: all diesel cars compatible

1 – Since 2010 all VW engines are E20 compatible, source: VW press release and 2008 US study "The Feasibility of 20% Ethanol Blends (vol) as a Motor Fuel" found no compatibility issues over selection of top selling models

Stock compatibility with new blends – illustrated example

- The model can track the share of stock compatible with new blends and then highest compatible blend is attributed to cars.
- Table below is an illustrated example of what cars will refill with, according to date of sales and main blend on offer.

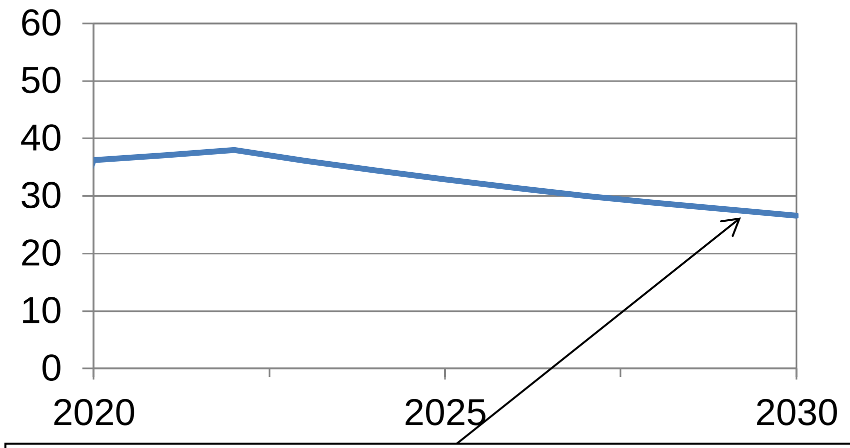
Main blend	E5	E10	E20
Timeframe: Cars:	2010-2015	2015-2020	2020-2030
Pre-2010 stock – not E10 compatible	E5	E5	E5
Pre-2010 stock – not E20 compatible	E5	E10	E10
Post-2010 sales	E5	E10[1]	For non compatible stock: E10 For compatible stock: E20[1]

Bu15 is equivalent to E10 and Bu24 to E15 in terms of engine compatibility

1 – Some cars will refill with E85 (vehicles sold from 2020), E85 use capped at 10% of total gasoline MJ

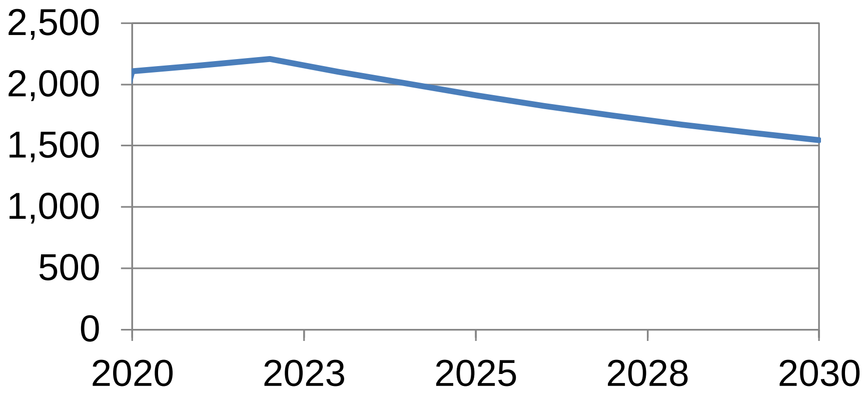
E85 supply and infrastructure

E85 supply, PJ



E85 demand follows gasoline demand reduction (improving fuel efficiency and increased use of diesel)

E85 supplied – l/station/day



Inputs relating to E85

- E85 consumption: capped at 10% of all gasoline MJ, constant over scenarios
- All new gasoline cars (ICE, HEV, PHEV) assumed flex-fuel from 2020

Outputs relating to E85

- To meet the E85 demand 1,600 stations must offer E85 fuel (over 8,900 stations currently in GB)
- The total cost of E85 stations rollout is around £53m which compares favourably with the cost of charging infrastructure