

Energy Options for Transport

Phase Two:

Energy systems implications and use of energy sources

Interim report, October 2015

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Summary

Context

Domestic transport accounts for ~25% of UK greenhouse gas (GHG) emissions. International shipping and aviation cause emissions of an extra ~8% on top of UK emissions (an extra third on top of transport emissions), but are currently excluded from national accounting. Demand for transport is likely to continue to grow: central scenarios for 2040 suggest increases of at least 25% for passenger travel and heavy freight, and ~75% for light freight. In order to achieve emissions cuts of 80% by 2050 (compared to 1990 levels), it will be necessary to significantly reduce transport's emissions intensity. These changes are taking place in the context of meeting other key priorities to address: affordability of mobility; air pollution; safety; flexibility of vehicles; and contributions to UK manufacturing and GDP. This project is considering the energy vectors for transport, including: a) interactions of future transport energy vectors with the wider energy sector; and b) the "best use" of energy sources between different sectors (transport, heat and electricity generation).

Focus on road transport

Road transport is the focus for transport decarbonisation, because it accounts for over 90% of UK domestic transport emissions (~67% for light road, and ~24% for heavy road). Light road transport (passenger cars and freight vans) has a clear pathway for decarbonisation: ~50% GHG emissions reductions are possible using light-weighting, energy efficient engines, and alternative liquid fuels; 80% reductions are challenging but possible, with increasing hybridisation or full electrification. However, better mechanisms are needed to ensure delivery of those benefits. The sector is aware of differences between tests and real-world conditions, and more realistic tests will be introduced in 2017. But recent discoveries of vehicle air pollution tests being deliberately circumvented by some manufacturers raises questions about how real-world tests of GHG should be implemented.

Heavy road transport is more difficult to decarbonise, and does not have a clear pathway to 50% or 80% reductions. Now they account for ~1/3 of UK road transport emissions, but in future they could be ~1/3 of all UK emissions (across all sectors) as other sectors' emissions fall. Heavy passenger vehicles (buses and coaches) can use some of the light road options, particularly hybridisation, and local buses can use electricity and hydrogen. The main challenge is posed by heavy goods vehicles (HGVs) and off-road vehicles (construction, agricultural and mining). Efficiency savings from better driving, aerodynamics and mechanical improvements could give up to 30% GHG emissions cuts in some cases; switching to natural gas (where applicable) could achieve ~10-20% cuts. Hybridisation is an option, but electrification and hydrogen pose challenges due to low power densities.

Solutions for heavy road vehicles could emerge from other transport modes. For example, aviation requires liquid fuels, and hence will have to develop low-carbon liquid fuels that could then be applicable to other heavy transport. One useful characteristic of HGVs is their comparatively small number: they make up ~1.5% of the road transport fleet (~500,000, compared to ~29million cars), but cause ~26% of the road GHG emissions. This is firstly due to larger weights (vehicles and loads), so the HGV fleet has lower embedded GHG emissions. Secondly it is due to HGVs' high utilisation, so retrofitting and / or replacing one HGV has a significant impact on in-use GHG emissions. Furthermore, economic drivers can make HGV usage more predictable, and can mean that some changes can be achieved more easily than for cars via certain regulatory or financial levers; although it can be harder to spread best practice to smaller operators than to larger hauliers. Despite these characteristics of HGVs, it is not necessarily cheaper to achieve savings through HGVs than through cars, because the smaller number of HGVs reduces their economies of scale in production.

Approaches to decarbonisation

Three factors determine GHG emissions, and each offers opportunities to reduce GHG emissions; their applicability varies between the modes of transport (road, rail, shipping and aviation):

- **Behaviour:** how demand for mobility is met by transportation. Transport energy increases with mobility demand, but not linearly owing to technical factors such as drive cycles and behavioural factors such as mode switching in response to congestion. Users can make more efficient use of transport, including reducing distances travelled. Operators of vehicles can adopt more efficient approaches (e.g. reduced speed), but this can have limited (or non-enduring) impacts. Of perhaps more interest are emerging models of ownership and usage. Shared ownership could reduce the number of vehicles (and hence embedded emissions) and improve utilisation. Shared use could reduce the volume of vehicle traffic.
- **Energy efficiency:** how efficiently energy sources are translated into energy vectors and then into useful motion of vehicles. Light-weight materials could reduce vehicles' energy demand (but advanced materials can have higher embedded emissions), and internal combustion engine (ICE) efficiency could increase including with some hybridisation; all told, these measures could reduce GHG emissions for liquid fuel cars by 30-40% by 2030. Electric vehicles (EVs) and hydrogen fuel cell electric vehicles (FCEVs) have higher motor efficiency (albeit higher weight), but currently have large energy losses in their upstream processes.
- **Emissions intensity:** how much GHG is emitted for each unit of energy provided. Biofuels and synthetic fuels for ICE vehicles have similar in-use GHG emissions to those for liquid fossil fuels, but life-cycle GHG emissions are lower (but some require the use of low-carbon electricity and / or carbon capture and storage (CCS) in fuel manufacturing). HGVs and buses can be designed (or converted) to use methane (natural gas or bio-methane), offering ~10-20% lower in-use GHG emissions (but methane leakage can negate this). EVs and FCEVs have no in-use GHG emissions; their life-cycle GHG emissions currently high due to the energy intensity of the processes, but there are opportunities for improvement using low-carbon electricity. Hybrids using liquid fuels and electricity offer intermediate benefits.

Interactions between energy vectors and the wider energy sector

The implementation of solutions for energy vectors in the transport sector will affect interactions between transport and the wider energy sector. Issues can be grouped into three categories:

- **Solutions require technological breakthrough that would affect interactions:**
 - High-density, low-cost batteries would allow long-distance EVs and increase uptake.
 - A new energy vector option for HGVs (e.g. large volumes of low-carbon liquid fuels, or cost-effective on-road charging) would change interactions with energy sector.
- **Solutions are achievable, but level of interaction is dependent upon other developments:**
 - EVs (and FCEVs) add demand for low-carbon electricity, whose outlook is uncertain.
 - EVs and storage are linked: EVs' batteries can help balance variable renewables with demand; but charging EVs could require network storage to address grid constraints.
 - CCS will be needed for chemical processing of some biofuels and synthetic fuels, for non-electrolysis hydrogen, and possibly for low-carbon power for EVs.
- **Solutions are available, but wider uptake (that will increase interactions) requires strategy:**
 - Short range EVs will require modified user behaviour (e.g. uses for more frequent / longer stops, or car sharing), or energy infrastructure (e.g. more charging points).
 - EVs will increase networks' power flows, requiring combinations of reinforcements, time-of-use tariffs (e.g. night-time at home), and storage (e.g. motorway services).
 - EV and FCEV life-cycle energy can be reduced by improved efficiency in upstream electricity generation, e.g. modern CCGTs, wind and solar.

- Introducing higher biofuel blends requires industry-wide agreement and long lead-times, due to implications for fuel suppliers and engine manufacturers.
- Reduced sales of liquid fuels could threaten the “universal coverage” of refuelling stations, and could put costs onto poorer customers that are more likely to be using older, less efficient cars, and less likely to be using new EVs, hybrids, etc.
- Natural gas can be provided to individual hauliers’ depots by extending the local gas transmission systems (or adding compressors to distribution systems), but the incremental nature might not give confidence to other customers. HGVs could add to the complexity of balancing the gas networks (but depots could provide storage).
- Hydrogen produced centrally would require piped networks. New networks would be expensive. Network companies are experimenting in repurposing gas grids, but they would have lower power flows (due to hydrogen’s lower energy density), and they could raise trade-offs with bio methane, and also with existing gas customers.
- Hydrogen produced locally requires utilities, e.g.: from water by electrolysis it uses the electricity grid (or on-site renewables) and water; or it uses gas for SMR.
- Hydrogen can be a versatile material: an energy vector for several energy demand sectors; an energy store; an intermediate step between energy sources and vectors, and between different energy vectors. Whilst this could allow some elegant technical solutions, inter-markets operations add complexity and financial risks.

“Best uses” of energy sources

Most energy sources have different potential uses, raising questions about the “best use” of energy sources, e.g. the energy vector into which they should be translated, and the sector in which they should be used. This is currently being studied, and broad considerations include:

- Scale of the energy sources: how much of each resource could be available to the UK, taking account of production potential, international, demand, etc.?
- Scale of the energy demand: how much energy demand there could conceivably be from transport, under a range of scenarios, and how does this compare with other sectors?
- Impacts of processes: how much energy is used (and what are the levels of GHG and pollutants) in converting energy sources into energy vectors?
- Limitations: which transport modes are limited in their choice of energy vectors?

Interim conclusions

Interim conclusions are that the following developments are necessary in the short-term to facilitate future transport energy options:

- Ensure that key regulatory mechanisms (e.g. new car tests from 2017, and also HGVs) are effective in ensuring that achievable benefits are delivered in practice.
- Determine how HGV energy efficiency (e.g. vehicle preparation, driving methods, routing and logistics) can be adopted widely throughout the fleet (not just by large hauliers).
- Develop energy vectors for HGVs, including from other heavy transport modes (e.g. aviation) and building on existing studies (e.g. DfT-ETI Low Carbon Truck Trials).
- Demonstrate and deploy CCS, for electrical generation and for chemical production of fuels.
- Deploy low carbon electricity (whether renewables, nuclear or CCS) to bring about the GHG benefits of electric (and hydrogen) transport.
- If large-scale uptake of natural gas or hydrogen is desired, develop strategic infrastructure plans to increase confidence for commercial initiatives.

Next steps

This project is developing scenarios to illustrate opportunities and issues that could arise from certain decarbonisation pathways, in particular: a) interactions of energy vectors with the wider energy sector; and b) the “best use” of energy sources. The work will progress through the following steps:

- Transport demand (by category including growth scenarios);
- Assumptions (efficiency improvements (for passengers and freight) and lifecycle impacts);
- Targets (including any differences between modes);
- Energy use scenarios that meet these targets;
- Economic implications and impacts on other sectors, including
 - o Interactions with wider energy sector;
 - o “Best use” of energy sources

The conclusions and recommendations are being developed, focusing on short-term steps needed to reach end goals, e.g.: areas for research, or identifying regulatory of market failures.

The report will be finalised for publication in January 2016.

DRAFT

1. Introduction

This project is highlighting the impacts of different lower-carbon energy vectors for transport. Phase One of the project produced a report summarising the options; Phase Two is focussing on light and heavy road transport, to analyse four main options (liquid fuels, gaseous carbon fuels, hydrogen, and electricity), in order to answer two broad questions:

1. What are the likely outcomes of different future energy vectors for transport?
2. Are there any indications of the “best use” of different energy sources?

The project investigates the impacts of each energy vector upon the wider energy sector. This is done in three stages, so as to highlight the technological and non-technological factors:

- comparing with today’s use of liquid fossil fuels: to highlight some of the challenges that could face supply chains and infrastructure (e.g. primary energy needed for each option);
- considering future energy demand: taking into account likely improvements in technical factors (e.g. upstream GHG intensity, drivetrain energy efficiency, light-weighting, etc.);
- considering future mobility: taking into account possible (and emerging) changes in use (e.g. transport users’ behaviour, vehicle ownership models, etc.).

The project is considering published scenarios, transport roadmaps, and scenarios derived by the steering group, to consider potential impacts of energy mixes. Outputs will include observations on:

- combinations of technologies that can give 80% GHG emissions cuts, and their economics;
- impacts upon the wider energy sector (e.g. EVs’ electricity demand and peak demand);
- limitations placed on the use of each energy source (e.g. pipeline pressure needed for CNG limit its use to only certain areas of the UK);
- interactions that would necessitate key developments elsewhere in the sector (e.g. EVs would benefit from better storage and from CCS power plants);
- any indications of a “best use” of energy sources (e.g. at present, it is more energy efficient to use wood in power stations than to convert it to 2nd gen biofuels; but biofuels offer greater flexibility), and how these indicators could be “traded off”.

Results are presented so as to deliver key messages, without debates over precise details, e.g.:

- quadrant diagrams to show trade-offs for energy options (e.g. GHG reductions and costs);
- charts showing key parameters changing over time (e.g. GHG intensity of fuels);
- Pareto analysis to rank options, including for different years.

The project’s conclusions and recommendations are being developed, focussing on short-term measures that are necessary for longer-term results. They can be grouped according to:

- technological breakthrough would be beneficial, requiring R&D action (e.g. energy storage);
- solution is achievable, but depends upon other developments (e.g. low-carbon electricity);
- solution is being used now, but wider uptake could require some strategic direction.

This report is structured as follows:

- Section 0 presents an overview of transport demand scenarios;
- Section 4 considers impacts of energy vectors in terms of GHG emissions, costs and energy;
- Section 4 discusses interactions between energy vectors and the wider energy sector;
- Section 5 will consider these impacts and interactions under different scenarios, to seek indications of “best uses” of energy sources (i.e. to produce particular energy vectors).

2. Scenarios of future transport demand

This section summarises key points about possible future transport demand, from published scenarios. Scenarios are not intended as accurate forecasts, but are useful for considering possible future trends; it is notable that energy trends in recent decades have fallen outside the range of many previous scenarios.¹

Figure 1 illustrates historical and possible future changes in transport energy demand, globally, in Europe and in the UK. The chart highlights changes in energy demand compared to 2010 (the most recent year for which multiple key publications are available), because this helps to emphasise potential future changes in terms of recent changes and current capacity. This chart summarises published future scenarios² into two broad categories:

- a) business as usual (BAU): liquid fossil fuels continue to be used extensively in long-term;
- b) EVs / FCEVs: electric vehicles (EVs) have a major role by ~2030; then out to 2050, either EVs continue to be used or are replaced by hydrogen fuel cell electric vehicles (FCEVs).

All scenarios of transport energy are based around two key drivers:

- Demand for mobility: increased by wealth and population that mean that more people can afford more passenger transport and more goods and services that require freight transport.
- Energy efficiency: the efficiency with which energy sources are transformed into useful motion in order to meet mobility demand.

Broad observations about future transport energy demand include:

- Transport energy demand today is higher than in 1990 (baseline for GHG emissions) in all regions of the world, weakened due to the recent recession, but is still on an upward trend.
- Future changes in global energy demand will be strongly affected by counties with large populations and rapidly growing economies.
- Energy demand is likely to continue to rise (especially under business as usual), but could peak at around 2020 in Europe (2030 globally), depending upon the rate of uptake of more efficient vehicles and fuels (e.g. EVs and FCEVs) in place of internal combustion engines.

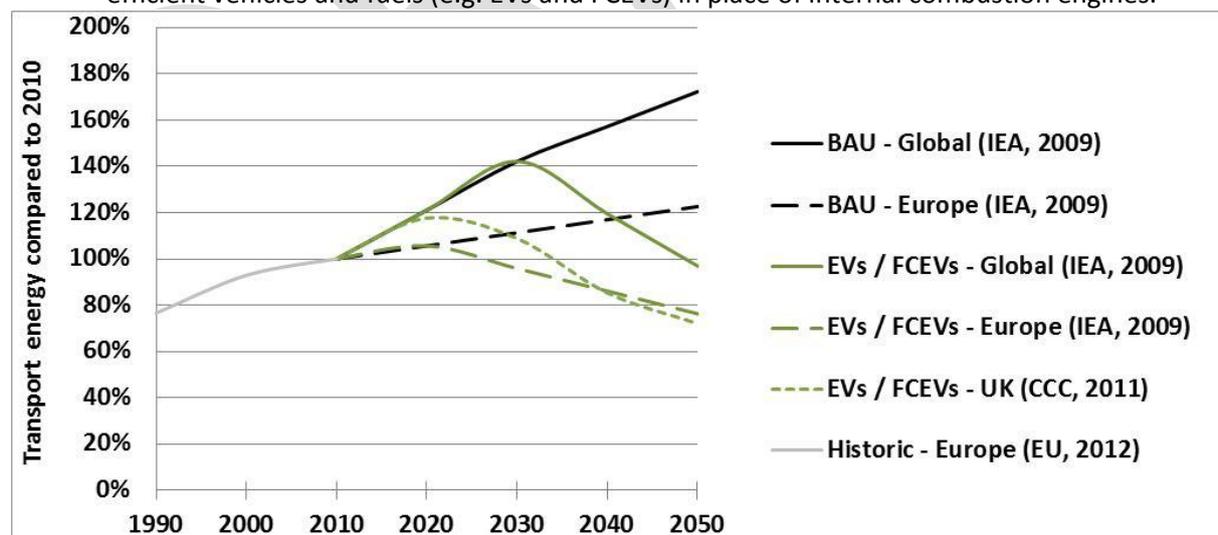


Figure 1: Energy demand for transport (global, Europe and UK), as percentage of energy demand in 2010, under future scenarios: a) business as usual; and b) significant use of EVs and / or FCEVs.

¹ Reflecting on Scenarios. UKERC Energy Systems Theme Working Paper (UKERC, 2014)

² Data from: Transport Energy and CO₂ (IEA, 2009); Bioenergy review (CCC, 2011); EU Transport Figures (EU Commission, 2012).

Global transport energy is dominated by road, including in the UK; as noted above, energy demand is driven by mobility demand and energy efficiency. These, in turn, are affected by underlying factors. Demand for mobility is affected by social patterns, manufacturing output, and affordability (which is a factor of transport costs and customer's available funds). Energy efficiency is affected by the vehicles' efficiency, by the upstream energy production processes, and by the embedded energy of vehicles and infrastructure. The following charts illustrate UK road transport data for mobility demand and energy efficiency.

Figure 2 illustrates mobility demand, split into passenger travel and freight transport (light freight vehicles and heavy goods vehicles (HGVs)).³ Key observations include:

- UK transport demand is expected to grow to 2040, with central scenarios suggesting increases of at least 25% for passengers and heavy freight, and ~75% for light freight.
- These scenarios try to account for changes in utilisation (e.g. the loading factor for freight vehicles, and the occupancy rates for cars), but there is considerable uncertainty about these issues, including the possible impacts of emerging models for ownership and use.⁴

These possible levels of future mobility demand are central to considerations of future energy options for transport. Firstly, there is the expectation in society sufficient energy will be available, whatever the levels of demand; this report considers options for improving the energy efficiency of mobility (at various points in the energy supply chain). Secondly, demand scales the impacts on GHG emissions and other key criteria (e.g. costs and air pollution).

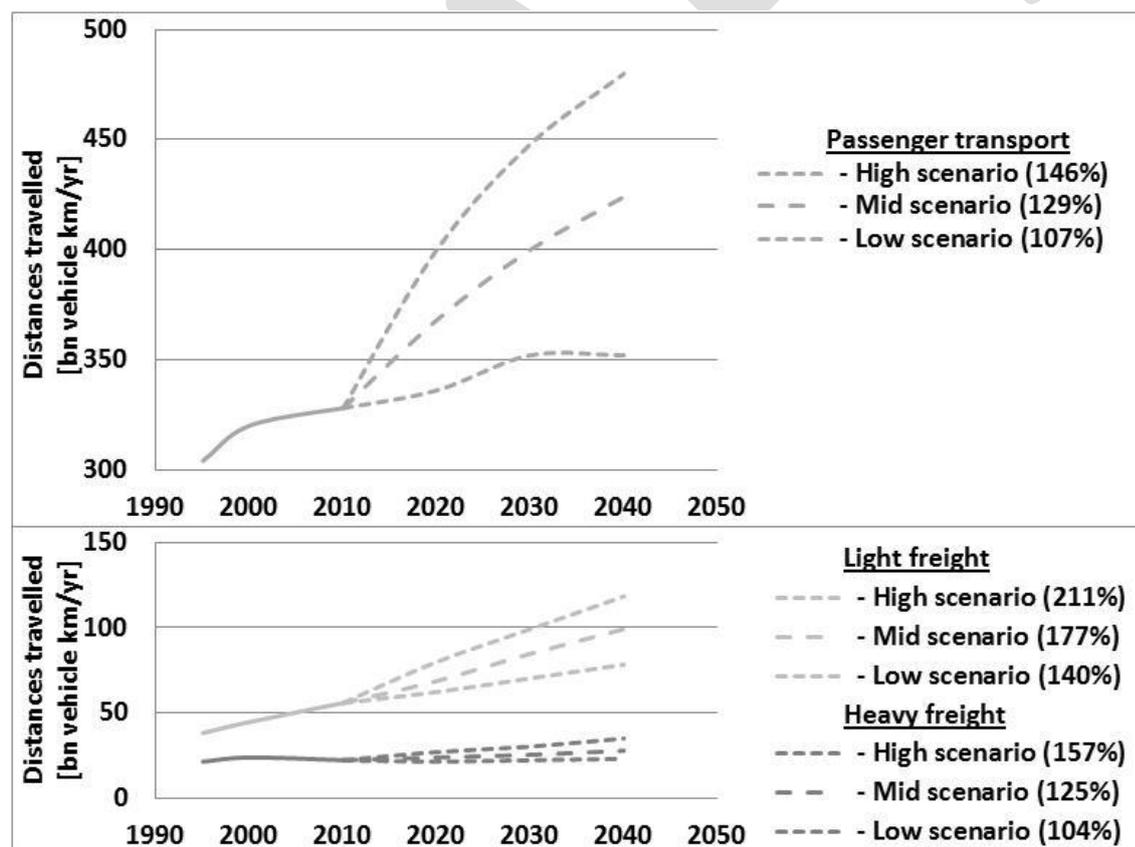


Figure 2: Historical data and future scenarios for UK road transport⁵

³ These three data types are presented in units of "billion vehicle km per year"; this unit indicates road usage, but does not allow direct comparison of energy because of the differing masses and efficiencies of vehicles.

⁴ Understanding the drivers of road travel: current trends in and factors behind roads use (DfT, 2015)

This section will also briefly review potential future changes to the ownership and use of vehicles, including:

- Changes in road transport that are not yet fully understood^{6 7}
- Mobility demand,⁸ and new ways of meeting that demand;
 - o Turnover of fleet^{9 10 11 12}
 - o Ownership models, including shared ownership (potential reductions in vehicle numbers);
- Logistics,^{13 14} including multi-modal freight,¹⁵ shared resources, and navigation;¹⁶
- Automation,^{17 18 19} including issues with complexity,²⁰ risk from cyber attack,²¹ and benefits when combined with shared use;²²

⁵ Data from: Road Traffic Forecast 2015 (DfT, 2015)

⁶ For example, see analysis in: Reducing emissions and preparing for climate change – 2015 Progress Report to Parliament, p126-127 (CCC, 2015)

⁷ DfT study on van use is due to be published in 2015.

⁸ See, for example: Reducing emissions and preparing for climate change – 2015 Progress Report to Parliament, p125 (CCC, 2015)

⁹ See discussion in: Reducing emissions and preparing for climate change – 2015 Progress Report to Parliament, p125 (CCC, 2015) [Refs to be added re. turnover data]

¹⁰ SMMT data: www.statista.com/statistics/299951/average-age-of-cars-on-the-road-in-the-united-kingdom/

¹¹ See briefing note: End-of-Life Vehicle (ELV) processing (SMMT, 2011)

¹² www.smmt.co.uk/2014-sustainability/environmental-performance/end-life-vehicles/

¹³ Logistics Carbon Reduction Scheme (LCRS) by Freight Transport Association

¹⁴ Reducing emissions and preparing for climate change – 2015 Progress Report to Parliament, p13 (CCC, 2015)

¹⁵ For example, could freight trans-shipping outside towns into electric distribution vehicles help with gas powering of vehicles?

¹⁶ [Ref: Interview for this project: ~10% of delivery emissions are due to re-delivery.]

¹⁷ See, for example: LUTZ Pathfinder pod in Milton Keynes

¹⁸ WEpod in The Netherlands

¹⁹ Auto Council Roadmap

²⁰ <http://www.thetimes.co.uk/tto/business/industries/transport/article4557901.ece>

²¹ See recent cases of hacking of cars' electronics.

²² http://www.smart2zero.com/en/autonomous-taxis-would-be-green-and-cost-effective-says-study.html?cmp_id=7&news_id=10005963&vID=1859&from_mail=1

3. Impacts of energy options

Life-cycles

When assessing outcomes from energy sources and vehicles it is necessary to consider stages from across the life-cycles (as illustrated in Figure 3), particularly in cases in which different impacts occur at different stages. For example, for liquid fossil fuels, most of the GHG emissions occur at the point of use; but the means for addressing these emissions lie mainly upstream in energy production and vehicle manufacture (where significant costs are incurred). This report does not present all of these factors at all of these stages; rather, it focuses on the most significant issues for each energy option.

Energy options for transport have to first of all be assessed against certain key technical criteria:

- energy density and portability: to allow sufficient range between refuelling;
- speed of refuelling: particularly important if done more frequently.

Energy options then have to be assessed against a range of factors. These are discussed in more detail in the report on Phase One; key factors are:

- Priorities for the transport sector
 - o Mobility, costs and affordability;
 - o Emissions: GHG and air pollution;
 - o Safety: achieved by reduced travel, avoided accidents, and collision protection;
 - o Flexibility of vehicles for: short/long journeys; good performance at range of speeds;
- Interactions with the wider energy sector, e.g.:
 - o availability of, and competition for, fuels (inc. life-cycle energy efficiency);
 - o use of infrastructure: pressure on existing, and costs of new.
- Interactions with other sectors, and wider issues e.g.:
 - o land use for production of biofuels or other resources;
 - o chemical feed stocks for production of synthetic fuels or other chemicals;
 - o disposal and recycling for used vehicles and infrastructure;
 - o contribution to UK GDP (e.g. through sales of energy and vehicles).

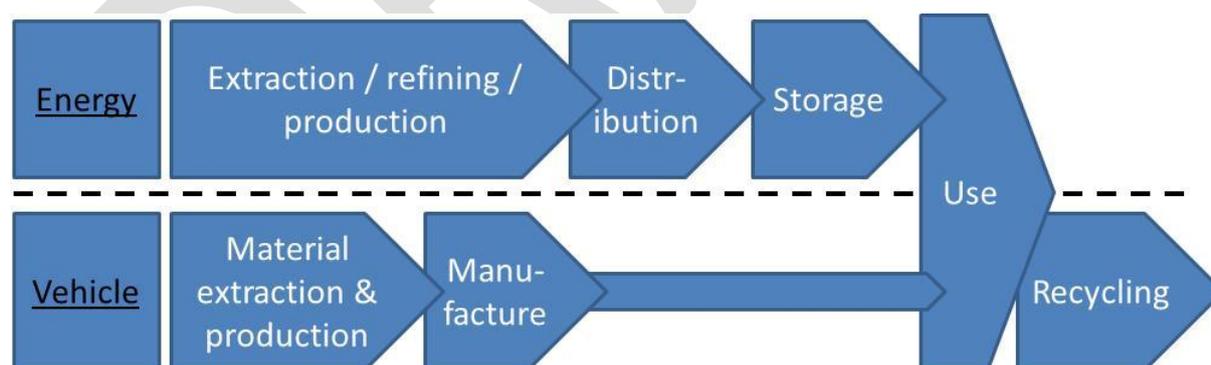


Figure 3: Stages in life-cycle of energy sources and vehicles.

Emissions of greenhouse gases and air pollution

The need to drastically reduce greenhouse gas emissions is the main driver for changes to transport energy. Whilst other issues also require changes (e.g. air quality can be improved by developing cleaner fuels and more efficient engines), GHG mitigation is larger and more wide-ranging. Issues with the measurement of emissions of GHG and air pollution are discussed below, but there is broadly accepted data about the GHG emissions intensities that can be realistically achieved at present. These are illustrated in Figure 4; key points include:

- Natural gas offers modest GHG reductions (10-20% for combustion): a dual fuel CNG-diesel vehicle saves up to 15% CO₂ compared to an equivalent diesel vehicle, and 60-90% if using bio-methane.²³ However, methane slippage can add to GHG emissions,²⁴ and is being studied.²⁵ Methane has other benefits, including lower lifetime costs and less air pollution.
- Biofuels offer lower emissions because their production includes processes that absorb CO₂ from the atmosphere (e.g. crop growth) that offset some of the CO₂ emitted in-use. GHG emissions savings for first generation crop-based biofuels depend upon the source, land-use impacts, production methods, etc., and can be negative. First generation biofuels from waste (used cooking oil, UCO) can save ~83%,²⁶ but the resource is limited. Second generation (or “advanced”) biofuels could offer similar savings, but studies are ongoing.²⁷
- Synthetic fuels GHG emissions are highly dependent upon fuel processing, and might rely upon CCS to achieve low GHG emissions.
- Electricity GHG emissions are dependent upon the fuel mix, and are currently ~390g/kWh in the UK²⁸ (unless self-generation, e.g. from on-site PV). However, EVs’ engines high efficiency means that they use less energy per km, and hence overall GHG emission can be lower.
- Hydrogen’s GHG emissions are dependent upon the production method. Emissions are very low when using electrolysis with renewable electricity, but are comparable to fossil fuels when using the steam methane reforming (current the most widely-used method).

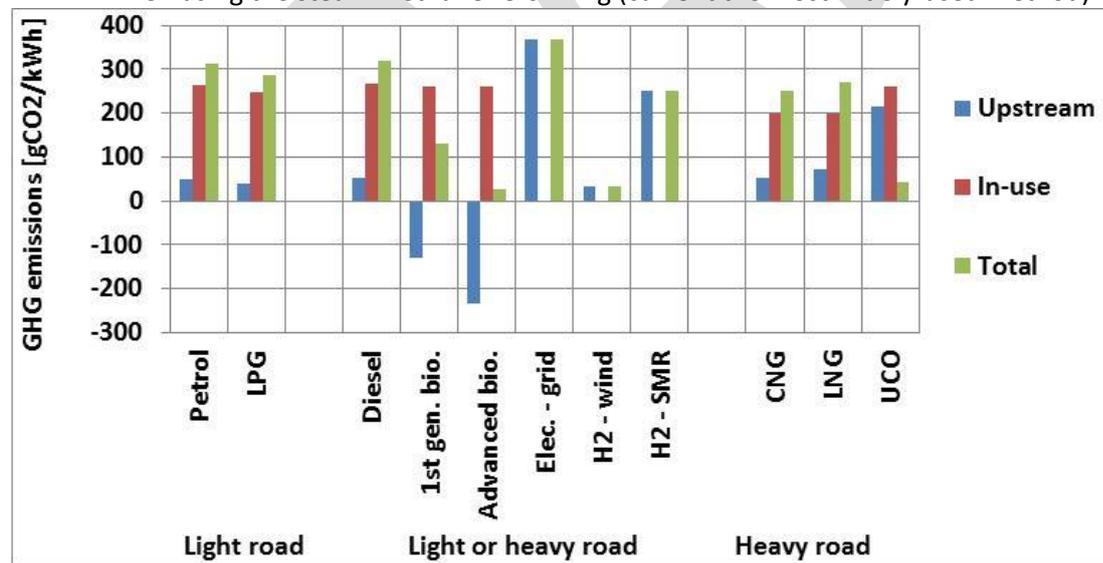


Figure 4: GHG emissions intensity for road transport energy options.²⁹

²³ See, for example: Waste and Gaseous Fuels in Transport – Final Report (Ricardo-AEA, 2014); and Annex to Low Emission HGV Task Force recommendations on the use of natural gas and biomethane in HGVs (DfT, 2014)

²⁴ See, for example: Report to Parliament (CCC, 2015)

²⁵ Gas Well-to-Motion study (ETI, ongoing)

²⁶ Low Carbon Truck Trial (2015)

²⁷ The sustainability of liquid biofuels – a collaborative metastudy (RAEng, for UK Government, beginning 2015)

²⁸ UK grid mix in 2014-15 was 386gCO₂/kWh. [Ref. to be added]

The air pollution impacts of transport energy options can be distinguished between local air pollution (i.e. causes harm in high concentrations at roadsides), remote (i.e. produced at sites such as power stations and refineries, and dissipates before reaching populated areas), and those pollutants that cause harm over wider distances.

More data will be provided in later drafts of this report. For now, it is noted that there is one particularly significant trade-off between emissions of GHG and emissions of air pollution. Internal combustion engines are more efficient if designed to operate at higher temperatures. However, higher engine temperatures increase the production of nitrous oxide (NO_x) air pollution.

As noted, there are currently issues with the measurement of emissions of GHG and air pollution; these include:

- EU regulations measure only tail-pipe emissions (i.e. tank to wheel) of CO₂ and pollutants such as NO_x for new cars, not life-cycle emissions (well-to-wheel).
- It is widely acknowledged that idealised test cycles do not accurately reflect real-world driving cycles. Also, some manufacturers make modifications to vehicles for tests, that again are unrealistic: some are within the letter (if not the spirit) of the rules. Studies have assessed the impact of test drive cycles and car modifications on GHG emissions³⁰ and air pollution,³¹ and there is broad consensus on the need for realistic tests, which will be introduced from 2017.³²
- There have also been testing practices that have circumvented the rules by illegal methods, e.g. “defeat device” software that changes engine performance to pass emissions tests.³³
- Currently there are no EU GHG emissions targets for new HGVs, but there is mounting pressure for these to be introduced.³⁴ The EU is developing a measurement tool³⁵ to model life-cycle GHG emissions, in a realistic manner (details of implementation are due in late 2015 or early 2016).

As well as regulating emissions for individual vehicles, it is possible to estimate overall emissions for the UK’s transport fleets. There are different methods of assessment that give slightly differing answers.

- The top-down approach is use fuel sales data to calculate energy consumption, and (using models of drive cycles) to calculate distances, emissions, air pollution, etc.
- The bottom-up approach is to use surveys of transport behaviour and models of each type of journey to estimate the overall distances, energy demand, GHG emissions, etc. To help address the gaps in the evidence for transport use, DfT has an ongoing programme of research.³⁶

²⁹ Various refs. inc.: Greet Model (Argonne National Laboratory, 2013); Natural gas emissions (SGI, 2015); WTW report (JRC, 2014); Biomass sector review for the Carbon Trust (Carbon Trust, 2005)

³⁰ Travelcard Nederland BV data source document: fuel consumption of Dutch passengers cars in business use 2004-2012 (TNO, 2013)

³¹ Don't Breathe Here: Tackling air pollution from vehicles (T&E, 2015)

³² [Ref. to be added: new EU emissions tests]

³³ See press coverage in late 2015 about VW’s defeat device affecting diesel cars in the USA (and possibly petrol cars and possibly other countries).

³⁴ [Refs. to be added, e.g. CCC, 2015]

³⁵ Vehicle Energy consumption Calculation Tool (VECTO). See: Development and validation of a methodology for monitoring and certification of greenhouse gas emissions from heavy duty vehicles through vehicle simulation (report for EU Commission, 2014)

³⁶ Understanding the drivers of road travel: current trends in and factors behind roads use (DfT, 2015)

Costs of vehicles, fuels and infrastructure

The switch away from non-fossil fuels can incur costs, or offer savings. The impacts depend upon the technology used; and the accrual of impacts to different groups depends upon how costs are allocated and the timeframe of the assessment.

Figure 5 presents typical costs: the two axes show costs for vehicle owners (vehicle costs and fuel price); and the size of data points gives a measure of the costs of point-of-sale energy infrastructure (i.e. fuelling stations and charging points).³⁷ The values are broadly similar for light and heavy road vehicles (noting that gas is applicable to heavy vehicles, and electricity to light vehicles).³⁸

The data will be analysed in more detail in the scenarios being developed, to consider overall costs and benefits to understand:

- break-even conditions for different options (e.g. about two years for gas HGVs);
- distribution of costs between different groups (e.g. reinforcements to electricity grids to accommodate charging EVs are socialised between electricity customers);
- effects of fiscal instruments (e.g. taxes and incentives).

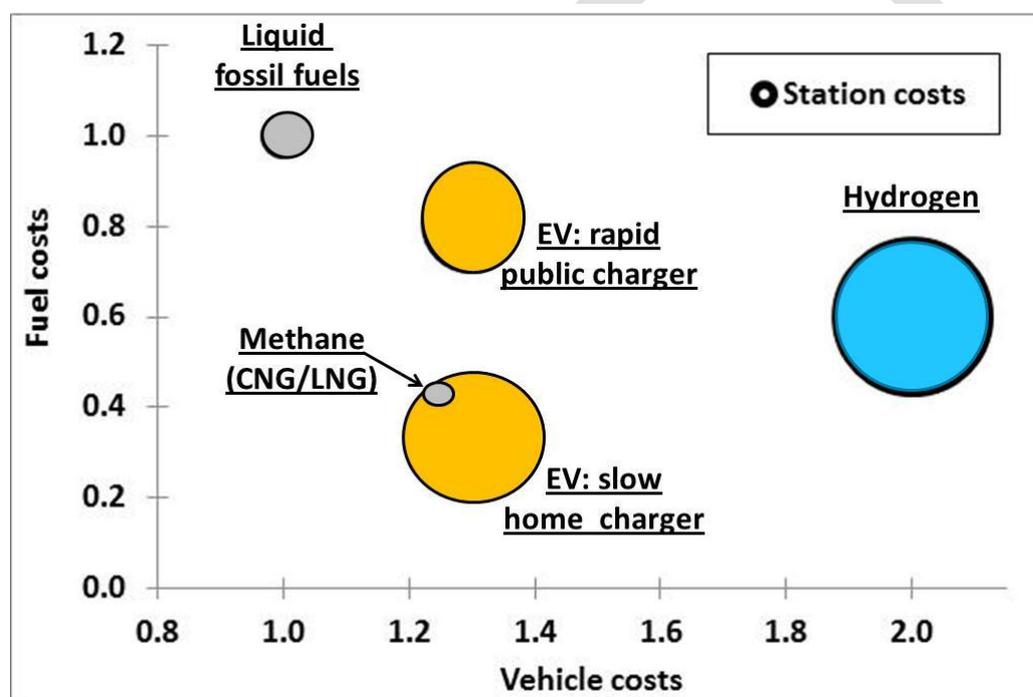


Figure 5: Costs and output of point-of-sale infrastructure and fuel prices³⁹

³⁷ All values are normalised to costs for liquid fossil fuels i.e.: cost of a conventional vehicle = 1; cost of 1kWh of kinetic energy from liquid fossil fuels = 1 (i.e. accounting for vehicle efficiency); and cost of a station supply 1kWh of energy per year = 1 (area of circle).

³⁸ Data is shown for energy, as opposed to distance travelled, so as to allow comparison of between different modes: e.g. an HGV uses much more energy per mile than a car does, and not all energy vectors are applicable to both modes (e.g. only HGVs can CNG/LNG, and only light vehicles can realistically use electricity).

³⁹ Data from a range of sources, including: Annex to the Low Emission HGV Task Force recommendations on the use of natural gas and biomethane in HGVs (DfT, 2014); Low Carbon Truck Trials (ETI, ongoing); Page 8 of Annex 4 (CCC, 2015); Production costs of alternative transportation fuels (IEA, 2013); Global EV outlook (IEA, 2013); trade associations for energy vectors; documentation for vehicles; etc.

For now, the following general observations can be made:

- Vehicle costs:⁴⁰
 - Liquid fossil fuel vehicles are cheapest, due to more decades of development, simpler materials, and mass production.
 - Compared to conventional vehicles, EVs and gas HGVs are roughly a half to a third more expensive, and hydrogen FCEVs are roughly twice as expensive.

- Fuel costs:⁴¹
 - At present, liquid fossil fuels are the most expensive;⁴² this includes taxes that are currently a larger proportion for fossil fuel costs, and could change for energy vectors in future.
 - Electric cars' refuelling costs can depend strongly upon the business model. If a home charger can be paid for upfront, and then the fuel costs are ~2p/mile. But the costs of a public charger will be recovered through the fuel costs, putting them up to ~10p/mile, although some companies offer unlimited charging for a fixed annual fee.⁴³

- Costs of point-of-sale infrastructure:⁴⁴
 - Electric cars can use rapid or slow chargers, that can be located either at home or in public; of the four combinations, this chart shows the two most likely (slow at home, and rapid public). Home chargers are cheaper (~£1,000 each), but are likely to be used less (by only one car); public chargers are more expensive, but are likely to be used by more cars.⁴⁵

⁴⁰ Grants are not included here, so some values are higher than the present sale prices.

⁴¹ Fuel costs include all upstream costs (passed to customers), e.g. refineries, power stations, distribution, etc.

⁴² Fuel costs for liquid fossil fuels are averaged for petrol and diesel; disaggregated diesel costs are lower.

⁴³ Ref: Bollore business plan in London

⁴⁴ These infrastructure costs do not include upstream assets (e.g. refineries, power stations, distribution methods, etc.); these will be considered in a future draft of this report.

⁴⁵ At present, utilisation of public charging points is hampered by: different payment methods and connections, and by locations that are uncoordinated or silly (e.g. slow chargers in short-stay car parks).

Energy use over life-cycle

Any energy option for transport has to be able to provide the necessary energy to meet demand for mobility; but there will also be a number other energy requirements throughout the life-cycles of the energy source and the vehicles. It is important to consider the total of these energy requirements, across the life-cycles: they determine demand for energy resources; they affect the use of infrastructure (which is explored in more detail later in this report); and they are considerations in judgements about the “best use” of different energy sources. Figure 6 illustrates current values for the energy uses of different energy options for road transport,⁴⁶ (noting that some options are not applicable to both heavy and light vehicles), including the life-cycles of both the vehicles and of their energy sources, divided into five elements:

- Required motion: energy that is finally translated into useful motion of vehicles to meet mobility demand, determined by weight and speed.
- Vehicle in-use losses:⁴⁷ energy that ends up as heat due to inefficiencies (e.g. from internal combustion engines or batteries); these are higher for internal combustion engines.
- Fuel conversion: energy used to convert one fuel to another (e.g. fuels used to generate to electricity, electricity used to generate hydrogen),⁴⁸ or state (e.g. compression or liquefaction of natural gas).
- Extraction, refining, etc.: energy used to obtain raw materials (e.g. crude oil, or plant matter) and produce a useful fuel (e.g. liquid fossil fuels, or biofuels).
- Vehicle embedded energy: energy used in the manufacture of vehicles;⁴⁹ these are a higher proportion of life-cycle energy for EVs and FCEVs (and disposal of vehicles⁵⁰ can be significant e.g. recycling of batteries).⁵¹ Operation and maintenance adds a little energy.

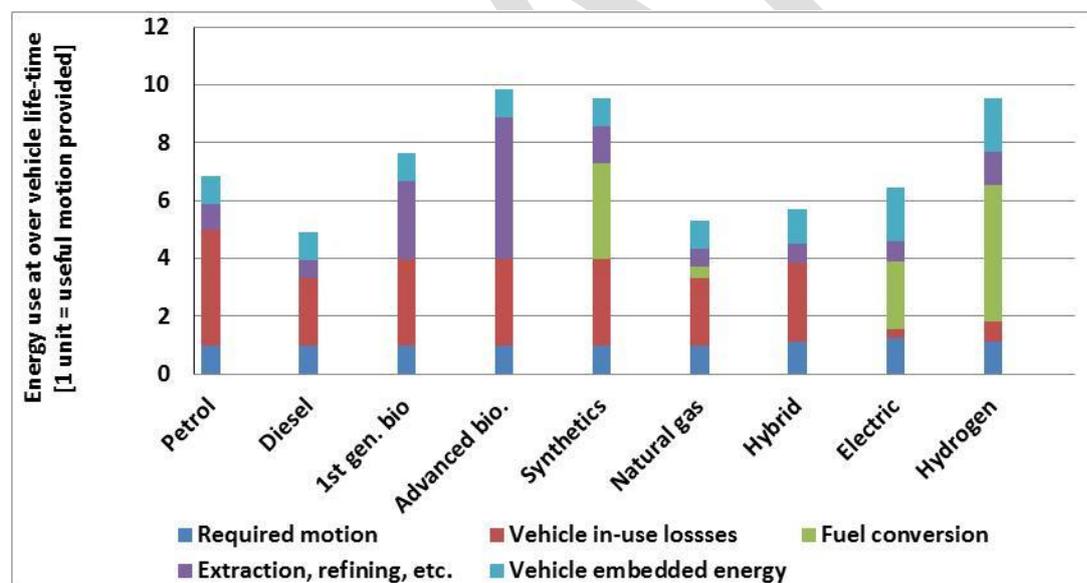


Figure 6: Energy used over life-cycle of a light road vehicle, including vehicle’s embedded energy and fuel’s life-cycle energy uses (normalised so that 1 unit equals current useful output energy).

⁴⁶ This data necessarily includes some simplifications and illustrative values from ranges of estimates.

⁴⁷ Engine efficiency of internal combustion engines is lower for petrol than for diesel. Vehicle efficiency for biofuels and synthetic fuels is averaged over light and heavy road vehicles.

⁴⁸ For simplicity, any fuel processing involved in fossil fuels or biofuels is treated here as part of extraction, refining, etc.; only major changes in energy vector are included under fuel conversion.

⁴⁹ SMMT Sustainability Rpt, & www.theguardian.com/environment/2009/aug/17/car-scrap-energy-efficiency

⁵⁰ See, for example: www.smmt.co.uk/2014-sustainability/environmental-performance/end-life-vehicles/

⁵¹ See, for example: Greet 2 Study (Argonne National Laboratory, work in progress as of September 2015)

Figure 7 summarises data the life-cycle energy uses of vehicles and energy sources. Values are normalised such that one unit is the amount of energy of motion (i.e. useful energy for mobility). For example, to manufacture a fossil car takes almost as much energy as the vehicle's motion over its lifetime; and the fuel's life-cycle (refining, etc.) accounts for five times as much as the motion. Figure 7 also notes where energy efficiencies could be improved (indicated by arrows), e.g. more efficient power stations would reduce EVs' and plug-in hybrid's energy impacts. It does not illustrate light-weighting (discussed in the bullet points). Light-weighting, mechanical efficiency and hybridisation could reduce light road GHG intensity by ~30-40% by 2030, but options are likely to be exhausted by 2030 for established technologies that have already exploited many options, whereas less-developed technologies could find more scope for efficiencies. Key points include:

- Energy required for motion is affected by the energy source, e.g. hybrids and EVs are heavier, but higher energy density batteries could be developed. Light road vehicles' weight could be reduced by a third; some of this would have no negative impacts, but some approaches would increase embedded emissions (see below). There are opportunities to reduce aerodynamic drag and internal mechanical resistance. For HGVs, overall efficiency improvements could amount to ~30% by 2030.⁵²
- In-use losses can continue to improve for all vehicle types (e.g. improved engine efficiency), hence reducing total energy demand and upstream energy.
- Fuel conversion efficiency is already quite efficient in some cases (e.g. 70-90% for hydrogen electrolysis), but less so for others (e.g. ~30-40% for producing electricity, but higher with renewables and new CCGTs), and there is uncertainty about how efficient other processes could become (e.g. for synthetic fuels). Energy for this stage is usually provided by another energy vector, so the fuel being produced is not used, but there is net energy use.⁵³
- Extraction, refining, etc. improvements are less likely for well-established energy sources, but are anticipated for developing energy sources (e.g. second generation biofuels, hydrogen, and electricity production for an evolving grid mix).
- Vehicle embedded energy (used in vehicle manufacture)⁵⁴ is determined partly by the mass of material used (so can be reduced by improved designs), but also by the types of materials (advanced lightweight materials can reduce in-use energy, but increase embedded energy).⁵⁵ It is also affected by the energy sources, e.g.: higher for hybrids and EVs due to battery production, and lower for smaller engines. Embedded energy is a smaller proportion of HGVs' lifetime energy due to higher utilisation.

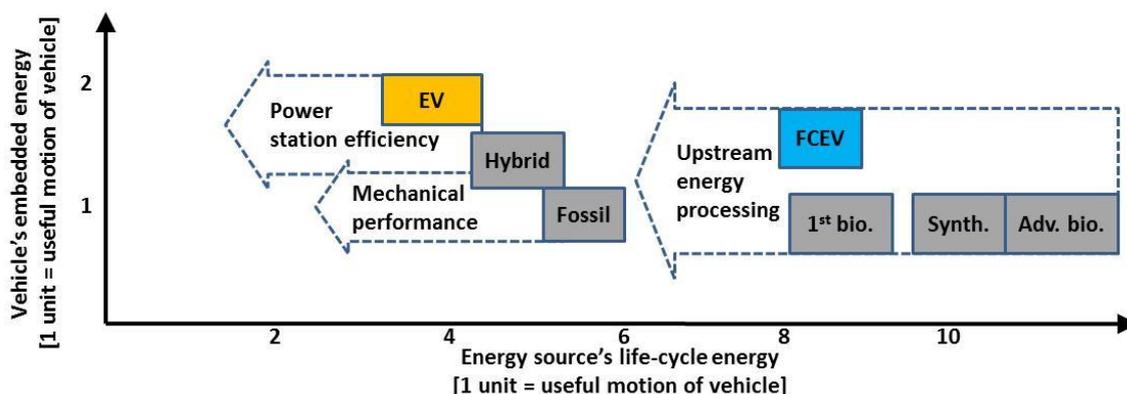


Figure 7: Life-cycle energy requirements of energy sources and vehicles.

⁵² See, for example: HGV study (ETI, 2014)

⁵³ See WTW rpt (JRC, 2014), p5

⁵⁴ Assuming 160,000 miles travelled, embedded energy is ~15-20% of total for ICes and up to 50% for EVs.

⁵⁵ Aluminium takes nine times more energy to produce than steel; and carbon fibre is at least double that. See, for example: Lightweight, heavy impact (McKinsey, 2012)

4. Interactions with wider energy sector

Moving to transport energy sources other than liquid fossil fuels is changing the way that transport interacts with the wider energy sector. This section sets out some of the main implications of each transport energy option (liquid fuels, gaseous carbon fuels, hydrogen and electricity).

Range and refuelling

In order to provide flexible mobility, an energy option is expected to satisfy two key criteria: the range between refuelling has been several hundred miles for extra-urban travel; and the time taken to refuel has been a few minutes.⁵⁶ Figure 8 illustrates these criteria for the four main energy options for road transport.⁵⁷

- Some energy options (in particular electrical batteries) currently limit vehicles' flexibility (less so for some models under development)⁵⁸ and hence require users to modify their behaviour, or alternatively require changes to energy infrastructure. Shorter ranges mean that journeys have to be planned more carefully to incorporate recharging stops; if this proved to be acceptable to motorists then charging points would need to be at more locations. Longer recharging times would mean that motorists on longer trips would have to stop for longer, so service stations might start to offer more services (e.g. desk space for working). Longer recharging would also mean that vehicles would not always be immediately available for journeys; this could be addressed in some cases by different user/ownership models (e.g. car clubs to make fully-charged vehicles more readily available).
- At the other extreme, some energy options could provide mobility without such limitations: for electrical networks (e.g. overhead wires or inductive charging), range is limitless and refuelling is unnecessary.

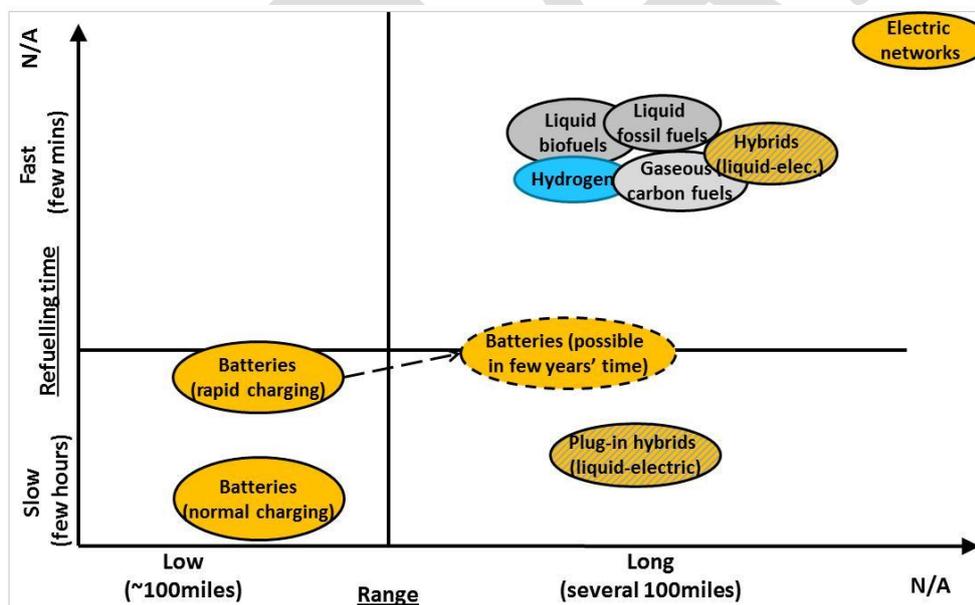


Figure 8: Basic criteria for road transport: range between refuelling, and time to refuel.⁵⁹

⁵⁶ Power flow of liquid fuel pumps at a fuelling station can be ~10MW, much higher than some other options.

⁵⁷ [References to be added]

⁵⁸ See, for example, the proposed "Porsche Mission E".

⁵⁹ Note that values for liquid fuels, hydrogen and non-plug-in hybrids) are similar: relative positions on this diagram are partly due to limited presentation space.

Liquid fuels

From a technical point of view, biofuels and synthetic fuels probably offer the simplest option, as a comparable replacement for liquid fossil fuels: they have similar (albeit slightly lower) energy densities, and they are easily portable. However, they do face certain challenges. The main technical issue is compatibility, which has implications for how these fuels could be deployed. Blends are compatible in small proportions without requiring modifications to distribution infrastructure or engines. At higher blends, engine modifications are required, which can then limit the use of other blends and pure fossil fuels. Any decision to move to a higher blend requires industry-wide agreement and long lead-times: it has large implications (and risks) for fuel suppliers (most forecourts sell only two versions of each fuel, e.g. standard and premium petrol) and engine manufacturers (for whom new models take several years to develop).

Drop-in fuels of synthetic fuels and some biofuels can be used as direct replacements for fossil fuels, requiring no engine modifications even at high proportions. Examples include fuels produced from: biomass, coal, or natural gas. Fuel can be produced from CO₂ and water, using renewable power, but requires either extra energy demand (e.g. to separate CO₂ from air) or a natural source (e.g. volcanic vents). Production methods for synthetic fuels are more complex than alternatives, with higher energy demands and higher GHG emissions; CCS could be necessary to realise their benefits.

Despite challenges for biofuels and synthetic fuels, it is likely that liquid fuels (of whatever sort) will provide less transport energy than they do at present, with implications for the infrastructure. Reduced sales could threaten the “universal coverage” of refuelling stations, especially in rural areas. Reduced sales volumes could put costs onto poorer customers that are more likely to be using older, less efficient cars, and less likely to be using new EVs, hybrids, etc. These two issues would combine in rural areas with lower incomes.

Gaseous carbon fuels

Natural gas for HGVs and buses would require changes to distribution infrastructure. Liquefied natural gas (LNG) would be transported by road tankers from LNG import terminals; tanker loading facilities are available at National Grid’s Avonmouth and (since 2015) Isle of Grain LNG terminal (32-36 per day, at 40m³ each). UK has an extensive gas network that could be used to supply compressed natural gas (CNG) to fleet depots or public refuelling stations. However, its supply pressure for vehicles (300bar) is present only in the national transmission system (NTS) and the local transmission systems (LTS) which is located only in/around the Midlands. For CNG, there are two options. The gas transmission systems could be extended: under current arrangements, these are paid for by individual customer sites: the costs could dissuade uptake; and the incremental nature might not give confidence to other customers. A cheaper (but less energy efficient) method would be connecting sites to low pressure gas networks and using compressors and local storage.

Gas for HGVs would add to overall demand for gas in the UK; scenarios suggest perhaps 1.5% of UK demand by 2030⁶⁰ (discussed further in Section 5), and would have other interactions with the wider energy sector. Intra-day peak demand is easier to manage for gas than for electricity, because the gas networks provide large storage capacity, but inter-day gas balancing can be difficult on very cold winter days. HGVs could add to challenges of demand and balancing; or alternatively transport depots could provide some storage to feed back into the gas network to meet high demand.

⁶⁰ Future Energy Scenarios (National Grid, 2015)

Electricity

Electricity is presently suited to light vehicles and buses, for shorter distances; HGVs can use hybrid diesel-electric drivetrains, inductive charge-on-the-move, or overhead cables. There are challenges at several points of the value chain. For energy supply, electrification presently offers only small GHG emissions reductions compared to liquid fossil fuels, but large savings are expected if the grid continues to decarbonise. For infrastructure, there is a need for charging points in more locations, but limited markets to encourage deployment. Scenarios suggest that EVs could add ~1.4-4.6% to peak UK power demand by 2030.⁶¹ To manage the charging of electric vehicles will require investments in networks, including reinforcements to increase capacity: this is comparatively straight-forward for transmission; but for distribution is more complex and costly (and the allocation of costs depends upon the type of site). Alternatively, power flows can be managed within existing network capacity by using time-of-use tariffs and “smart grids”, e.g. to charge EVs at homes overnight when there is a large surplus of domestic capacity. Finally, power flows can be managed by using energy storage e.g.: battery swap schemes; or service stations charging on-site batteries overnight for then providing rapid charging for cars during the day⁶² (which also makes use of old EV batteries that cannot be easily recycled; but there is also the related issue of resource availability).

Hydrogen

Hydrogen has zero emissions of CO₂ at point of use,⁶³ and the main attraction for transport is fast refuelling (similar to liquid fuels), so the customer-side of fuelling infrastructure could function much as at present. However, significant changes (or additions) would be need on other infrastructure, with two distinct options. Hydrogen could be produced at central locations and tinkered or piped to refuelling points.. A new hydrogen pipe network would be expensive. Some gas network companies are experimenting in repurposing parts of the gas grids to transport hydrogen, raising trade-offs with using the networks for bio methane, and trade-offs between the needs of customers using hydrogen and gas. Or, hydrogen can be produced locally: either by electrolysis at a fuelling station, requiring a water supply and electricity grid reinforcements, (unless using onsite renewables); or by processing methane from the gas networks. Whatever the sources, the main issue is supply volumes, e.g. whether there could be sufficient low-carbon electricity or sufficient SMR with CCS.

An appeal of hydrogen is that it can service multiple markets.⁶⁴ Linkages between energy vectors offer opportunities to make better use of resources e.g.: produced using surplus renewable electricity; storing energy (with more flexibility than for batteries); and regenerating electricity later, either for remote locations, or more widely to meet peak demand.⁶⁵ In another example, hydrogen can be combined with atmospheric CO₂ to produce low-carbon methane or methanol. Linking between markets adds complexity and risk (e.g. fuels could be unavailable in the absence of sufficient contractual arrangements or price signals).⁶⁶ Also, hydrogen is a raw material for various sectors including with energy sector, e.g. most hydrogen is used in oil refining (e.g. desulphurisation, and accounting for 2% of UK energy demand), produced from methane with high GHG impacts.

⁶¹ Future Energy Scenarios (National Grid, 2015)

⁶² For more information, see, for example: <http://evalu8-ti.org.uk/>

⁶³ See further discussion in: H2 Mobility project (ongoing)

⁶⁴ See, for example, discussion in: New Lens Scenarios (Shell, 2013)

⁶⁵ Transferring between energy vectors reduces the overall energy efficiency (e.g. using electricity to produce hydrogen via electrolysis, and then using hydrogen fuel cells to generate electricity). However, it could possibly be cheaper than building peaking power plants that would be used for just a few hours each year.

⁶⁶ Such risks are also seen with existing fuels, e.g. see reports about UK diesel supplies (RAC Foundation, 2015).

5. Scenarios: interactions and “best uses”

This section considers impacts of different energy options, drawing upon previous sections that have considered the energy vectors for transport, to estimate the scale of the interactions with the wider energy sector. This section also considers uses of energy sources (e.g. biomaterial, renewable generation, nuclear generation) that can be translated into energy vectors for vehicles, to see whether any judgements can be made about the “best use” of each energy source.

Objectives and approach

The analysis for phase two of this project is focusing on light road vehicles and heavy road vehicles. The main energy options are illustrated in Figure 9, an “impact-confidence” chart presenting a view of potential emissions reductions (impact), and the level of confidence of delivering that impact. Drawing on the published scenarios, this project will develop a set of high-level scenarios to illustrate opportunities and issues that could arise from certain decarbonisation pathways. The work will progress through the following steps:

- Transport demand (by category including growth scenarios);
- Assumptions (efficiency improvements (for passengers and freight) and lifecycle impacts);
- Targets (including any differences between modes);
- Energy use scenarios that meet these targets;
- Economic implications and impacts on other sectors, including
 - o Interactions with wider energy sector;
 - o “Best use” of energy sources

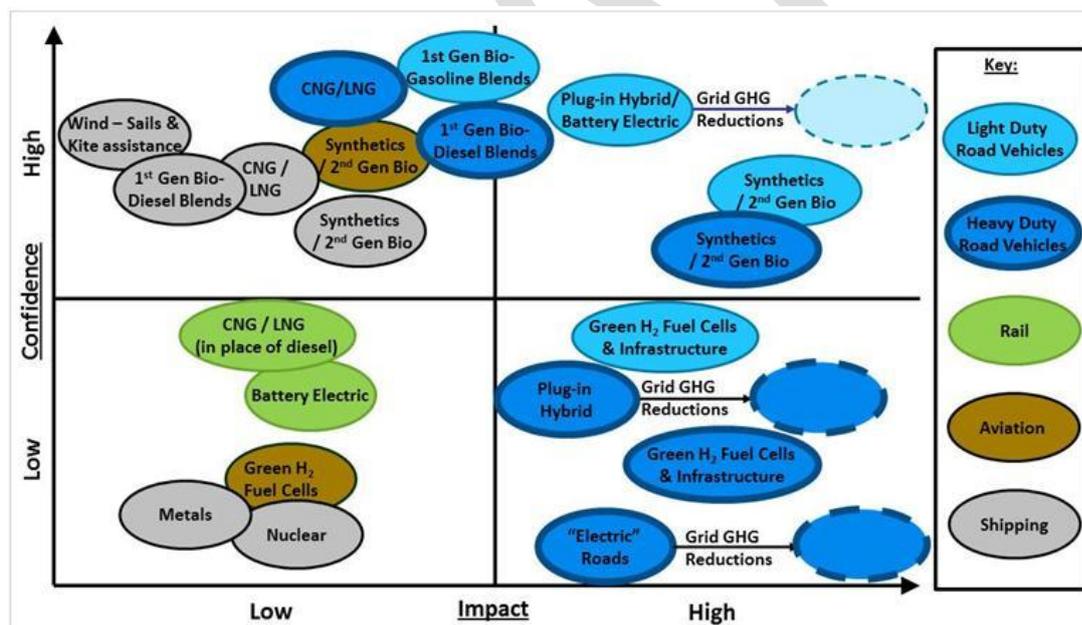


Figure 9: Impact-confidence chart of energy vector options for transport.

Interactions with the wider energy sector include issues such as:

- how future transport energy mixes to meet decarbonisation targets could impact upon the wider energy sector (e.g. all cars being EVs could double annual electricity demand);
- whether those interactions place any limits on the use of each energy source (e.g. pipeline pressure needed for CNG limit its use to only certain areas of the UK);
- which of those interactions would necessitate key developments elsewhere in the sector (e.g. EVs would benefit from better storage and from CCS power plants).

Issues around “best use” of energy sources can be complex, because each energy source can have multiple uses, and each route has to be assessed against multiple criteria that have to be weighed up. Figure 10 illustrates some of the main routes from energy sources to energy vectors, further interactions between processes, and the applications of energy vectors to different sectors.

Questions about “best use” include:

- For wood biomass, what are the trade-offs between the energy efficient option of burning it in power stations for electricity, burning it for heat production (in buildings or district heating), or converting it to second generation biofuels for transportation, or using elsewhere with CCS to get negative emissions,⁶⁷ or leaving wood as carbon stores?
- For waste, is the best use to make gas to burn to generate electricity, or to put it into the gas grid, or to incentivise for use in transport to displace diesel (with air quality benefits)?

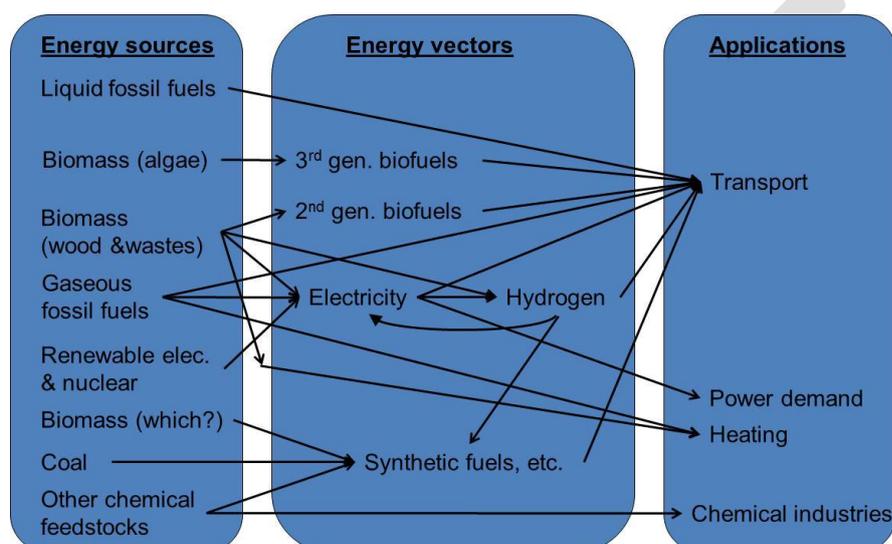


Figure 10: Routes from energy sources to energy vectors, and their applications

⁶⁷ Reducing emissions and preparing for climate change: 2015 Progress Report to Parliament – Annex 4: Transport (CCC, 2015)

Scale of energy demand sectors

There are various forecasts of market penetration of second generation biofuels,^{68 69 70} and of the output of their production facilities.^{71 72} Similarly, there are scenarios of uptake of natural gas for transport,^{73 74} EVs^{75 76 77 78}, and overall pathways of vehicle efficiency and fleet decarbonisation.^{79 80}^{81 82} These can be compared with demand for other transport fuels, and other uses of resources.

It is instructive to also consider examples of using energy sources to meet large volumes of demand, to get a sense of the comparative scales of end-use sectors. Figure 11 and Figure 12 present data about the energy demands natural gas and biomass if they are used for of different demand sectors. These examples are purely illustrative: it is unlikely that any one energy option will dominate in the near-to-medium term.⁸³ Observations include:

- If HGVs got all of their energy from natural gas, then this would add about 20% (100TWh) to the gas demand from heating and power; but this level of dominance is unlikely.
- If all light road vehicles were powered by electricity produced by gas, then this would double demand for gas power plants; the extra would be larger if the electricity was from biomass.

The examples noted above are unlikely in two ways.

- Firstly, it is unlikely that any one technology will be able to meet all needs for light or heavy road vehicles, and hence will not dominate as liquid fossil fuels do at present. However, it is possible that a technology could obtain a sufficiently large market share to give economies of scale that lower its costs to the point that other technologies are effectively locked out of the market (and customers for whom the technology was not ideally suited could be willing to change their operations and behaviour to be able to use the it).
- Secondly, future energy demand is unlikely to be the same as at present: energy intensity will fall due to technological improvements; energy intensity could also fall due to changes in mobility behaviour; however, demand for road transport could tend to increase overall impacts energy demand. Furthermore, the link between energy demand and GHG emissions (and other impacts) will change as the energy mixes evolve over the coming decades.

⁶⁸ Bioenergy review (CCC, 2011)

⁶⁹ Page 140, CCC, 2015

⁷⁰ Gallagher Review (2009)

⁷¹ New Lens Scenarios (Shell,2013)

⁷² Boosting the Contribution of Bioenergy to the EU Climate and Energy ambitions (European Industrial Bioenergy Initiative (EIBI), 2014)

⁷³ Future Energy Scenarios (National Grid, 2015)

⁷⁴ [Ref. to be added: UK natural gas vehicle trade association]

⁷⁵ Chapter 4 and Annex 4 of: Reducing emissions and preparing for climate change – 2015 Progress Report to Parliament, p125 (CCC, 2015)

⁷⁶ Fourth Carbon Budget Review – Technical report (CCC, 2013)

⁷⁷ Future Energy Scenarios (National Grid, 2015)

⁷⁸ Global EV outlook (IEA, 2013)

⁷⁹ The Carbon Plan: Delivering our low carbon future (HM Government, 2011)

⁸⁰ New Lens Scenarios (Shell,2013)

⁸¹ Auto Council Roadmap

⁸² ERTRAC Roadmap

⁸³ However, liquid fossil fuels currently provide ~97% of road transport energy; this dominance came about alongside the emerging market, from the start with very low demand. The low-carbon transition poses the very different challenge of changing the energy sources of a very large and well-established transport sector.

However, these examples do illustrate that issues could arise if relying too heavily upon one form of technology or one primary source of energy.

- From the point of view on energy vectors, if all light transport used only electricity, then its demand would be around 300TWh per year; this is the same present total electricity demand in the UK.
- From the point of view of energy sources, the UK uses natural gas for much of its energy: heating started using natural gas in the 1970s, and now uses 300TWh per year; power generation started using natural gas in the 1990s “dash for gas”, and now uses and 200TWh per year. Recent enthusiasm for shale gas could evolve into another “dash for gas”, including to replace coal power stations and to meet extra power demand from electric vehicles, hence increasing the UK’s dependence upon natural gas. If all HGVs used only natural gas would add about 120TWh of demand; although it more likely that many HGVs would be gas-diesel hybrids (e.g. current trials use ~30-50% methane or bio-methane)⁸⁴.

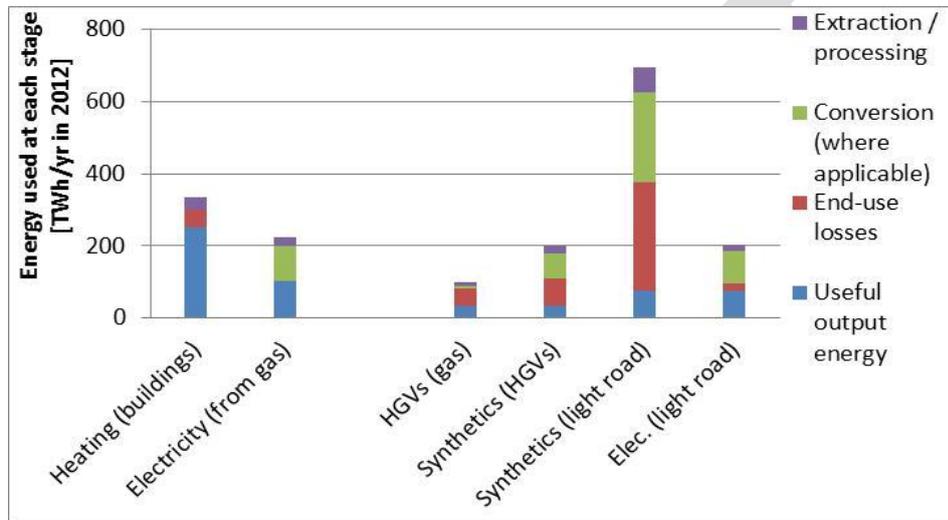


Figure 11: Energy that would be required if gas (e.g. natural gas or bio-methane) was used to meet entire energy demand of certain UK demand sectors. Heating buildings and generating electricity are actual values from 2012, for comparison.

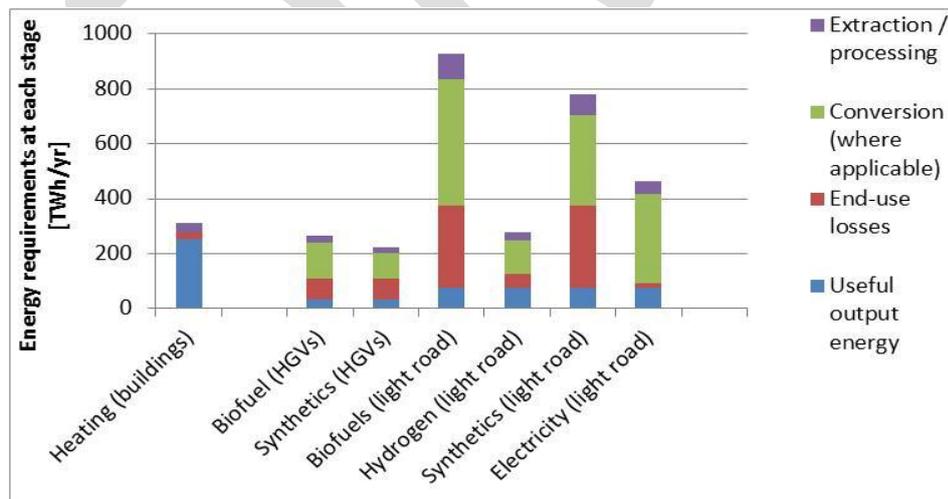


Figure 12: Energy that would be required if biomass (e.g. wood) was used to meet entire energy demand of certain UK demand sectors.

⁸⁴ Low Carbon Truck Trial (second report, 2015)

Scale of energy sources

This section will discuss in detail the availability of energy sources, to note any key constrictions that could limit their application. For example:

- Bio-energy sources:
 - o worldwide demand for second generation biofuels⁸⁵
 - o UK domestic production and imports^{86, 87, 88, 89, 90}
 - o waste resources^{91, 92}
- Hydrogen as an energy vector or an intermediate step: This is being considered in more detail in the ERP's project about hydrogen,⁹³ but key issues include:
 - o Could the best use of low-C hydrogen be to displace high-C hydrogen (from SMR) for refining?
 - o When could the UK have a surplus of electricity to for electrolysis, and what could be the cost effectiveness of having electrolyzers working under very low duty cycles?
 - o What is the viability of hydrogen generation from excess wind for transport if the UK has alternative solutions (e.g. lot of network electricity storage or DSR)?

Scenarios of future transport energy

This section will present a small number of high-level scenarios that incorporate:

- Transport demand, including effects of changing models of ownership and use;
- Technological improvements to vehicles and infrastructure;
- Availability of energy sources, and upstream improvements in fuel production;

Comparisons of options and "best uses"

This section will include comparisons between uses of energy sources and their scales, in order to allow commentary on the trade-offs and answers to the questions posed earlier in this section:

- Quadrant diagrams of key parameters, e.g. energy use, GHG, costs, air quality;
- Pareto analysis to rank uses for each key parameter;

⁸⁵ Technology Roadmap – Biofuels for Transport (IEA, 2011); and <https://www.iea.org/newsroomandevents/pressreleases/2011/april/biofuels-can-provide-up-to-27-of-world-transportation-fuel-by-2050-iea-report-.html>

⁸⁶ UK Bioenergy Strategy (DfT, DECC and Defra, 2012)

⁸⁷ UK and Global Bioenergy Resource – Final report (AEA, 2011)

⁸⁸ See: www.e4tech.com/en/consulting-projects.html#Bioenergy [Full reference to be added]

⁸⁹ Cross-government Bioenergy Strategy [reference details to be added]

⁹⁰ The sustainability of liquid biofuels – a collaborative metastudy (RAEng, for UK Government, beginning 2015)

⁹¹ Wasted: Europe's untapped resource – An assessment of advanced biofuels from wastes & residues (ICCT, IEEP and NFCC, 2014)

⁹² Biomethane for Transport from Landfill and Anaerobic Digestion (Ricardo AEA for DfT, 2015)

⁹³ Hydrogen report (ERP, not yet published)

6. Conclusions and interim recommendations

Road transport is the focus for decarbonisation efforts, because it accounts for over 90% of UK domestic transport emissions. Light road transport has a clear pathway for decarbonisation: ~50% GHG emissions reductions are possible using light-weighting, energy efficient engines, and alternative liquid fuels; 80% reductions are challenging but possible. Heavy road transport is more difficult to decarbonise, and does not have a clear pathway to 50% or 80% reductions.

Three factors determine GHG emissions, and each offers opportunities to reduce GHG emissions; their applicability varies between the modes of transport (road, rail, shipping and aviation):

- Behaviour: how demand for mobility is met by transportation.
- Energy efficiency: how efficiently energy sources are translated into energy vectors and then into useful motion of vehicles.
- Emissions intensity: how much GHG is emitted for each unit of energy provided.

The implementation of solutions for energy vectors in the transport sector will affect interactions between transport and the wider energy sector. Issues can be grouped into three categories:

- Solutions require technological breakthrough that would affect interactions (e.g. batteries for long-distance EVs);
- Solutions are achievable, but level of interaction is dependent upon other developments (e.g. CCS is needed for electrical generation and chemical production of some liquid fuels);
- Solutions are available, but wider uptake (increasing the interactions) requires strategy (e.g. natural gas for HGVs).

Most energy sources have different potential uses, raising questions about the “best use” of energy sources, e.g. the energy vector into which they should be translated, and the sector in which they should be used. This requires further study, but broad considerations include:

- Scale of the energy sources: how much of each resource could be available to the UK, taking account of production potential, international demand, etc.?
- Scale of the energy demand: how much energy demand there could conceivably be from transport, under a range of scenarios, and how does this compare with other sectors?
- Impacts of processes: how much energy is used (and what are the levels of GHG and pollutants) in converting energy sources into energy vectors?
- Limitations: which transport modes are limited in their choice of energy vectors?

This project is developing scenarios with which to consider in more detail: a) interactions of energy vectors with the wider energy sector; and b) the “best use” of energy sources. The conclusions and recommendations are being developed, focusing on short-term steps needed to reach end goals, e.g.: areas for research, or identifying regulatory or market failures. Interim conclusions are that the following developments are necessary in the short-term to facilitate future transport energy options:

- Ensure that key regulatory mechanisms (e.g. new car tests from 2017, and also HGVs) are effective in ensuring that achievable benefits are delivered in practice.
- Determine how HGV energy efficiency (e.g. vehicle preparation, driving methods, routing and logistics) can be adopted widely throughout the fleet (not just by large hauliers).
- Develop energy vectors for HGVs, including from other heavy transport modes (e.g. aviation) and building on existing studies (e.g. DfT-ETI Low Carbon Truck Trials).
- Demonstrate and deploy CCS, for electrical generation and for chemical production of fuels.
- Deploy low carbon electricity (whether renewables, nuclear or CCS) to bring about the GHG benefits of electric (and hydrogen) transport.
- If large-scale uptake of natural gas or hydrogen is desired, develop strategic infrastructure plans to increase confidence for commercial initiatives.