Life Cycle Assessment of Vehicle Fuels and Technologies

Report Summary
London Borough of Camden
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on behalf of London Borough of Camden

LCA Study – Report Summary

Sales of cleaner vehicle fuels and technologies are being driven by a growing awareness concerning the environmental costs of motoring, ever tightening regulated emission standards and by an increasing number of cleaner car models on the market. The government is supporting this transition and, although cleaner vehicles currently represent less than 0.1% of all UK light-duty sales,[1] has set the target that cleaner cars (defined as 'low carbon'; • 100g/km CO_2) should represent 10% of all car sales by 2012.[2,3]

Image courtesy of Greenergy

Figure 1 Taxi refuelling with 5% biodiesel

There has already been some success in introducing cleaner fuels and vehicles into the UK market. To date, over 100,000 cars have already been converted or manufactured to run on liquefied petroleum gas (LPG).[4] Electric vehicles have found niche applications, either as small city cars, as service utility vehicles (eg forklift trucks) or as milk-floats (which comprise the largest battery electric vehicle fleet in Europe). More recently, several models of petrol hybrid-electrics cars have become available in the UK with annual sales already exceeding those for battery-electric vehicles. Biofuels are also in the ascendancy. Supported by new EU legislation, biodiesel and bioethanol sales are increasing significantly and are likely to comprise around 6% of fuel sales (as blends) by 2010.[5]

Broadly speaking, the development of alternative options encompasses two approaches – these provide a useful way to categorise the options available. The first involves the development of cleaner fuels that can be used with conventional engines. The second approach has been to develop partial or complete alternatives to the internal combustion engine. Therefore, we can classify cleaner vehicles in one of two ways: according to the fuel and according to the technology. The main options are therefore as follows:

Cleaner vehicle fuels:

- Biofuels – fuels produced from plant or animal oils including biodiesel and bioethanol;
- Gaseous Fuels – fuels usually produced from fossil-fuel sources including compressed natural gas (CNG) and liquefied petroleum gas (LPG);
- Electricity – electricity can be generated using fossil or nuclear fuels, or from renewable sources;
- Hydrogen – like electricity, hydrogen is a secondary form of energy, which can be derived from renewable and non-renewable sources.

Cleaner vehicle technologies:

- Battery-Electric – electricity can be used to charge an on-board battery. When required, electrical energy is drawn from the cells and converted to motive power by the use of an electric motor;
- Hybrid-Electric – a conventional engine is used to generate electricity on-board the vehicle. Motive power is provided via a mechanical drive-train and/or using electric motors via an electric drive;
- Fuel Cell-Electric – if hydrogen and oxygen (from the air) are fed into a fuel cell, a voltage difference is produced which can be used to drive an electric current, which in turn can operate an electric motor. This can be used to power a fuel cell vehicle.

Life cycle assessment study

A large number of cleaner vehicle fuels and technologies are now commercially available. However, the complexity of comparing the emissions profiles of each of the options makes it difficult for the consumer, fleet manager or policy maker to decide the most appropriate vehicle fuel or technology for a particular application. Even at the policy maker level there may be a degree of uncertainty regarding the relative benefits of each cleaner option and the relative impacts of fuel and vehicle cycles.

For these reasons, the London Borough of Camden commissioned Ecolane Limited to conduct a desk-based research project to assess the life cycle environmental impacts of commercially available road vehicle fuels and technologies in the UK. This document summarises the main findings as described in full in the main report.[6] The evidence presented is based on existing reference data and includes: petrol, diesel, bioethanol, biodiesel, natural gas, liquefied petroleum gas, battery electric, and hybrid electric vehicles. The study focuses on passenger cars and light-duty vans, including car-derived vans. As previous comparative studies have done, the analysis includes an assessment of the environmental impacts associated with the *fuel cycle* (primary production, extraction, transportation, refining, and vehicle operation). Unlike other UK studies, the analysis also assesses the impacts associated with the *vehicle cycle* (vehicle manufacture, assembly and disposal).

Although the environmental impacts of fuel and vehicle life cycles include a wide range of resource, pollutant and land-use issues, the LCA study focuses exclusively on quantifying the extent and impacts of life cycle air-borne emissions arising from the fuel and vehicle cycles. The reason for this focus is due in part to the importance of air emissions in the context of road transport and also due to the time and resource limitations of the study. The air emissions assessed include the *regulated* emissions (carbon monoxide, oxides of nitrogen, hydrocarbons and particulates).[7] In addition, the three main greenhouse gases associated with road transport are assessed: carbon dioxide, nitrous oxide and methane.

Image courtesy of Toyota GB Ltd.

Figure 2 Toyota Prius II Petrol Hybrid

In addition to making emissions comparisons for each of the vehicle types considered, the LCA study also goes beyond an *inventory* phase and includes an *impact assessment* as part of the life cycle emission methodology. This is achieved by the use of the Environmental Rating Tool developed by the European Cleaner Drive Programme.[8] This rating system uses recognised 'external costs' to establish the relative weight to attach to different emissions – the external costs are values expressed in monetary terms that reflect the overall damage to the environment and to human health caused by emissions. Using the Cleaner Drive rating system, the level of environmental impact is expressed as a score between 0-100 (for greenhouse gases, regulated pollutants and total impact); the lower the score, the less the environmental impact.[9]

Life cycle assessment results

One of the key findings of the LCA study is that vehicle size is as important a determinator of emission impact as fuel/technology type – the results show that vehicle size is strongly correlated to overall environmental impact as quantified by the Cleaner Drive rating system (see Figure 4). Moving down one FISITA passenger car category typically reduces the Total Cleaner Drive rating by 6-8 points[10] – for a medium sized passenger car, this equates to a reduction in the total life cycle environmental impact of around 12%-16%. The importance of vehicle size is due to the effect of fuel economy on vehicle emissions, and also to the fact that higher fuel use requires an increase in fuel production energy which in turn leads to increased emissions. In addition, the vehicle cycle also contributes to this correlation – larger vehicles (that tend to have higher fuel use) require more materials and assembly energy during manufacture.

Focusing on the impact of cleaner fuels/technologies, the LCA analysis shows that all the alternative options analysed offer some degree of reduction in life cycle environmental impact (see Figure 5). Using conventional petrol as a baseline, for most vehicle classes, mineral diesel is equivalent within confidence limits. Compressed natural and liquefied petroleum gas cases are rated (for life cycle environmental impact) at approximately 18%-19% below the baseline, and biodiesel is rated 11%-24% lower than petrol (depending on vehicle class). Bioethanol, battery electric using average mix electricity and petrol-hybrids are the next cleanest cases at around 23%-26% lower. As expected, the renewable battery electric case is the cleanest according to the Cleaner Drive rating system and scores over 70% less than the petrol baseline. As can be seen from Figure 5, for many cases, the benefits offered by alternative fuels are due to a reduction in greenhouse gases *and* regulated emissions. However, although the biofuel and non-renewable battery electric options provide a significant greenhouse advantage over their conventional counterparts, they do so with a moderate worsening of life cycle regulated pollutants.

The findings of the LCA analysis of specific vehicle models show that, in those vehicle classes where available, the use of battery-electrics consistently result in the least overall environmental impact. Although in some cases this is true for battery electrics using average electricity mix, it is always the case if renewable energy is used for recharging. In the best case, as compared to a petrol baseline, the overall environmental impact is reduced by over 70%. Although currently, there are very few battery electric models available, two models of note are the Reva GWIZ in the Citycar category and the Citroen Berlingo Electrique (Small Family car and Car-derived van categories).

The findings also demonstrate the benefits of hybridisation. In particular, in those vehicle classes where they are commercially available, petrol hybrids (such as the Toyota Prius and the Lexus RX400h) provide significant reductions in overall environmental impact. Given that the Cleaner Drive rating system is weighted in favour of greenhouse gas emissions, and given the improvement in fuel economy of around a quarter offered by hybrids, the overall impact is reduced by around 26%. The Cleaner Drive analysis also shows that, in the event of diesel hybrids becoming available, they would also provide a significant reduction in overall environmental impact – with a possibly greater life cycle emission benefit than is the case for currently available petrol hybrid cars.

The two pure biofuels analysed by the LCA also offer consistently reduced overall environmental impacts. Across all vehicle classes, switching from mineral diesel (ULSD) to biodiesel reduces overall impacts by around 13% and changing from petrol (ULSP) to bioethanol reduces environmental impacts by 23%. However, it should be remembered that these benefits are estimated for 100% biofuels (ie E100 and B100). In practice, biofuel blends (eg E5, B5) are more likely to be available in the short-term.[11] Furthermore, there remains some uncertainty regarding the emissions data associated with biofuel production. For these reasons, the quantified biofuel benefits should be treated with caution.

The results of the specific LCA analysis show that, liquefied petroleum gas (LPG) and natural gas (CNG) vehicles still offer greenhouse gas and air quality benefits. As compared to a petrol baseline, the data analysed show (for passenger cars) an 18%-19% reduction in the overall environmental impact for the two road fuel gases.

Image courtesy of GoinGreen

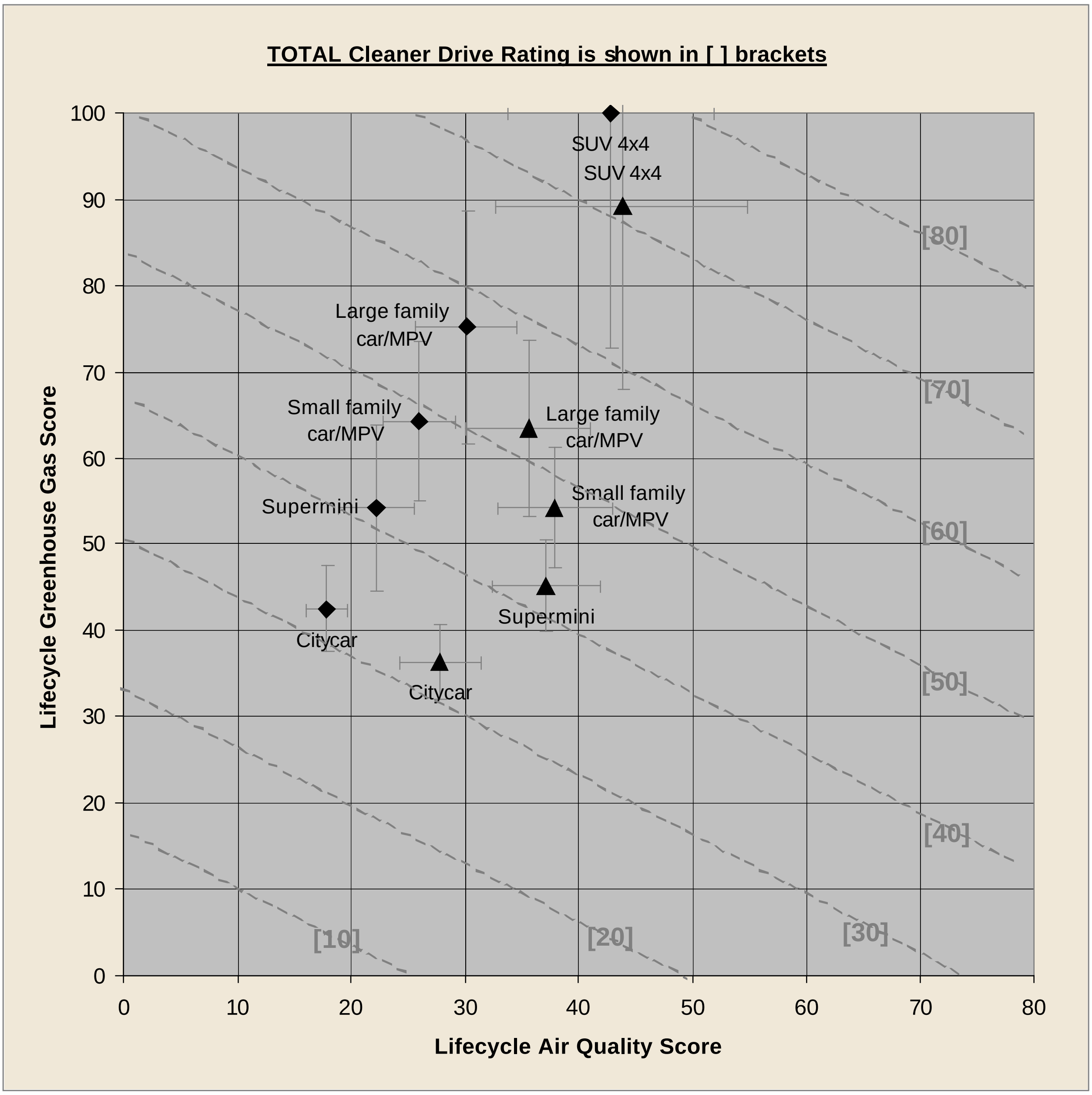
Figure 3 Reva G-WIZ battery-electric car

Regarding the sources of emissions, the results of the LCA analysis shows that, in most cases, the vehicle and fuel production stages account for around 20% of total lifetime greenhouse gas emissions – the emissions associated with fuel and vehicle production are roughly equal in magnitude. This is the case for conventional petrol and mineral diesel, the two road fuel gases and also for petrol-hybrids. However, this proportion does not hold true for biofuels, the emissions associated with fuel production being significantly increased. For battery electrics, vehicle manufacture and fuel production emissions account for all life cycle emissions, the vehicles being zero-emission in operation.

Considering the regulated emissions, apart from battery electrics, the vast majority of life cycle hydrocarbon emissions originate during fuel production. In contrast, (excluding battery electrics and bioethanol) a significant proportion of life cycle carbon monoxide emissions are generated during vehicle use. The picture for particulates and NOx is more complex. For non-diesel fuels, the majority of these two emissions are produced during fuel and vehicle production – for the two battery electric cases, fuel and vehicle manufacture emissions account for all life cycle impacts. For diesel fuels, a significant proportion of these two emissions are produced during vehicle operation.

The location of regulated emissions sources has implications for the environmental impact of the emitted pollutants – and one that is accounted for by the Cleaner Drive rating system. From the perspective of the life cycle analysis, with the exception of carbon monoxide, and particulates and NOx from vehicles using diesel fuels, the majority of regulated pollutants are emitted away from most major urban areas (unless a refinery, fuel processing or vehicle manufacturing plant lies within a populated region).

Figure 4 Cleaner Drive rating for cars according to vehicle size



KEY TO SYMBOLS

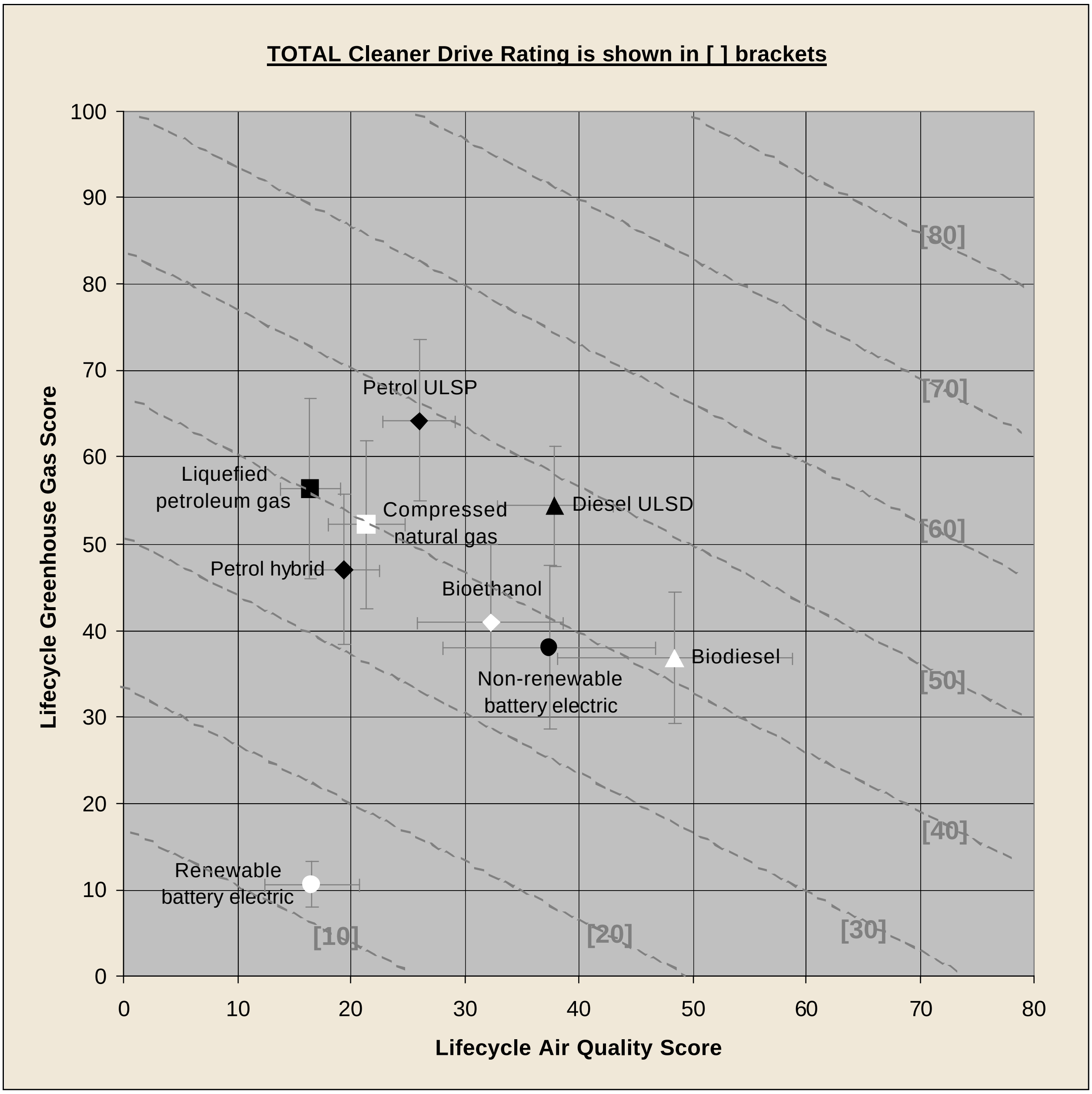
u ULSP Petrol
¯ E100 Bioethanol
p ULSD Diesel
r B100 Biodiesel

¢ Bi-fuel LPG
o Bi-fuel CNG
˜ Average mix BEV
™ Renewable BEV

Notes

Chart uses Cleaner Drive rating methodology as described in main report. For vehicles using ULSP, ULSD, LPG and CNG fuels, the chart shows Cleaner Drive scores based on emission data sourced from the Vehicle Certification Agency. For vehicles using biofuels, ratings are based on comparison of ULSP/bioethanol or ULSD/biodiesel as described in report. For battery-electric vehicles, Cleaner Drive scores are based on fuel economy data as published by manufacturers.

Figure 5 Cleaner Drive rating for cars according to fuel/technology



KEY TO SYMBOLS

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Notes and References

[1] According to the SMMT (2005), fewer than 500 cars sold in 2004 were classified as ‘low carbon’ (<100 gmsCO2/km) equating to the new ‘A’ VED band.

[2] Powering Future Vehicles. The Government Strategy. Department for Transport, July 2002, London.

[3] This equates to the order of 200,000 vehicle sales per year.

[4] Consultation on the TransportEnergy Clean Vehicle Grant Programme. Energy Saving Trust, London, 2004.

[5] Towards a UK strategy for Biofuels. Public consultation document, Department for Transport, London, 26 April 2004.

[6] The ‘Life Cycle Assessment of Vehicle Fuels and Technologies’ report in full was delivered to Camden Borough Council in March 2006, and due for publication in the public domain thereafter.

[7] Sulphur dioxide and nitrous oxide data are also sourced where available.

[8] For more information, see Appendix 3 of final report or visit the Cleaner Drive website at: www.cleaner-drive.com.

[9] Note that for consistency of presentation of charts within the final report, a reverse rating is used based on the Cleaner Drive score – this is simply the score subtracted from 100 (ie New score = 100 – Cleaner Drive score). This results in cleaner vehicles with lower emissions having a lower environmental rating.

[10] With the exception of the renewable battery-electric vehicle case which scores consistently low.

[11] In addition, the use of pure biofuels may require some engine modification and invalidate a vehicle’s warranty (see discussion of this issue in main report).