Acknowledgements

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The research contained in this report details work carried out jointly by the members of Workstream 13: Human Machine Interface (HMI) Engineering. The workstream is comprised of the following partners:

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Executive Summary

This report details research carried out within Workstream 13 (HMI Engineering) of the Low Carbon Vehicle Technology Project.

The introduction of Low Carbon Vehicles (LCVs) will present a range of new and unfamiliar technologies to the driver, and to maximise adoption it will be vital for automotive manufacturers to make the driver’s interaction experience with the Human Machine Interfaces (HMI) a positive and rewarding part of the overall LCV ownership experience. In the first case this means understanding the issues users have with current products, and identifying the pertinent design problems that need to be addressed. As such, the overall objective of the workstream is to:

*Identify the key HMI concerns and appropriate solutions specific to users of Low Carbon Vehicles*

To address this objective, the project is taking a user-centred approach to investigate the behaviour, needs, and opinions of LCV users. The research is split into three separate tasks, and this report details the findings from the first of these. It encompasses a review of currently existing HMI relevant to LCVs, as well as analyses of user blogs, published research, news articles, and road tests. In addition, learning has been included from technologies designed to encourage pro-environmental attitudes or behaviours of users. Known as eco-feedback technologies, these include the new generation of interfaces such as the Ford Smartgauge, and Chevrolet Volt displays.

The scope of the work is restricted to non-commercial Hybrid electric vehicles (HEV), Plug-in Hybrid Electric Vehicles (PHEV), Range Extending Electric Vehicles (REEV), and Full Electric Vehicles (FEV).

Research questions and main findings

- What are the market trends in LCV telematics and HMI, and what solutions are available on current and near term vehicles?

In the next five years a strong trend will be the central role that telecommunications and rich information play in the LCV user experience. This will be particularly evident in FEVs where the integration of navigation systems with Global Positioning System (GPS) technology, and mobile communications will be needed to help users manage the whole charging process.

As greater amounts of information are required to be displayed, configurable instrument clusters will offer design flexibility by allowing contextual information to be shown that is relevant to the task in hand, whilst maintaining simplicity. Research shows that users find analogue displays easier to interpret than digital (i.e. numerical) displays.

Nearly all LCVs have power in/out gauges and battery state of charge (SoC) gauges, and providing these should be considered the minimum requirement. While over 70% of the former are needle and dial displays, there is not a clear consensus on the design of the latter. Needle and dial displays, and graphic representations of bars in a battery similar to a mobile phone are equally common. In certain situations such as understanding available range/SoC, an optimal solution may be to combine numerical and analogue information.

Although power flow displays are common in hybrid vehicles, there is a need to simplify the visualisation of the information if they are to fulfil their potential to educate drivers as to how their driving style influences efficiency. Linking this information to personal goals is an effective strategy.

The development of smartphone applications that allow remote monitoring and control of vehicle functions is likely to be a source of innovation for OEMs. From an...

“HMI and driver information in EVs [electric vehicles] is the new frontier that automobile designers should have their hands on” J.Mays, Ford Vice President of Global Design (Automotive Design, 2010)
LCV perspective the most common functions are being able to monitor the SoC, see the available vehicle range, monitor and control the charging process, and pre-condition the interior by controlling the climate control system.

- What learning from persuasive and eco-feedback research can be applied to LCV design?

Eco-feedback interfaces which specifically aim to encourage pro-environmental behaviour change such as driving more efficiently are starting to be introduced on LCVs, and are likely to become more commonplace. When applied within cars, fuel savings in the order of 6% to 15% can be achieved. For those OEMs that implement these systems well, this offers an opportunity to differentiate the brand, and provide real benefits to users.

Popular strategies to encourage behaviour change include goal setting, feedback of relevant information to the user, performance comparison between individuals and groups, or self-comparison, and provision of incentives (e.g. money saved). Combining goal-setting with feedback has proved to be a particularly effective strategy.

These principles have been most successfully applied in the Ford SmartGauge interface as found in the Fusion hybrid, and the LCD screens in the Chevrolet Volt. User feedback regarding the SmartGauge has been largely positive with drivers finding it rewarding, and useful in helping maximise fuel economy.

- What are the most important HMI related issues and behaviours that LCV users experience?

From users’ reports of their experiences with LCVs, a number of HMI related issues are commonly mentioned.

Overall, range anxiety amongst FEV drivers was the most prominent concern. This anxiety is prevalent in inexperienced drivers, however there is considerable evidence that with experience, range anxiety decreases as drivers learn more precisely how many miles a charge will last and factor this into their journey planning.

Feedback of all kinds is recognised as very important to the user experience, however the reliability of estimated range, and SoC figures are particularly crucial for LCV drivers. This information is intrinsically connected to feelings of range anxiety because it affects how much confidence users have in planning and completing their journeys, therefore better forecasting of these effects will be very beneficial. The projected range ideally needs to take account of environmental factors like temperature, traffic or road types (highways or smaller roads), as these can have a large influence on a vehicle’s performance.

“...I am getting very little to no charging. Sometimes this happens in the middle of the night and I wake up to just a 5% increase. So while the MINI E is charging I look for that blinking LED on the MINI E battery indicator to make sure its blinking, if not I then check the yellow box on the cable to see what it is doing. Then I do my little dance of re-plugging the cable in if it does not cycle, then I run out to the car to see how much I got or didn't get….I find myself constantly checking that MINI E LED, just like we glance at the range or % indicator when we drive. My Wife has pointed out I’m obsessed…I find myself re-checking about every 15-30 mins…I call this CHARGE ANXIETY.” (My Mini E: Mini E EVangelist - #402 2009b).

The process of charging also presented a number of problems for users. Principally these are related to vehicles failing to charge, and the stress this causes. In order to alleviate dissatisfaction, there is a strong case for providing better feedback of the charging process, with some kind of fault diagnosis to users. Another irritation for users was the location of the charging socket when it was on one side of the car, as this was found be many to be an inconvenience.

Throughout users’ reports, there were numerous examples of drivers adapting their behaviour when living with LCVs. These included strategies for planning routes, and reducing the use of secondary controls such as climate systems to conserve energy, as well as using regenerative braking rather than conventional brakes in order to extend the vehicle’s range. Described as ‘one foot’ driv-
ing, this style of driving proved to be very popular once owners had got used to it, and illustrates the potential for users to change the way they drive if it is deemed beneficial to them.

The main issues just described are summarised in the table below, together with the related design problems that OEMs need to consider when developing Low Carbon Vehicles. These will be investigated in more detail in the next phases of this project through interviews and questionnaires with participants in the West Midlands.

**Summary of main user issues and resulting HMI design problems**

<table>
<thead>
<tr>
<th>Category</th>
<th>Issue</th>
<th>Design problems raised from the research findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range Anxiety</td>
<td>Range anxiety due to fear of running out of charge</td>
<td>What are the realistic HMI changes/new features that OEMs can implement in order to reduce range anxiety?</td>
</tr>
<tr>
<td></td>
<td>Range anxiety reducing with experience</td>
<td>What are the realistic HMI changes/new features that OEMs can introduce to 'speed-up' this reduction in range anxiety?</td>
</tr>
<tr>
<td>Charging</td>
<td>Problems with charging</td>
<td>What is the optimal HMI design for vehicle charging feedback? Location on the vehicle? What charging states? Feedback time-out?</td>
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<tr>
<td></td>
<td>Frequency of charging</td>
<td>What is the best way that the OEM can remind (but not nag) the user to charge the vehicle? E.g. Location of feedback, frequency of feedback, conditional feedback etc.</td>
</tr>
<tr>
<td></td>
<td>Location of charging point</td>
<td>What is the best way for the OEM to inform the driver of the location of charging points in the near vicinity? Map, smartphone etc? Is information 'pushed'? What information should be given?</td>
</tr>
<tr>
<td>Feedback</td>
<td>Unreliable information about range and charging</td>
<td>What are the 'HMI rules' that any range or charging information should abide by in order to promote confidence in the data?</td>
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<tr>
<td></td>
<td>Lack of engine noise</td>
<td>What is the most appropriate method of compensating for the lack of engine noise as a form of driver feedback?</td>
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<tr>
<td>Adapting behaviour</td>
<td>Optimising range</td>
<td>In what way can drivers be encouraged to safely adapt their driving style or chosen routes, such that efficiency is improved?</td>
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<tr>
<td></td>
<td>One-foot driving</td>
<td>What are the implications (if any) of 'one-foot driving' on the design and engineering of the accelerator and braking pedals? It appears that the ability to drive using only one pedal is dependant on the severity of the regenerative braking</td>
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1. Introduction

1.1. The research need

It is now widely accepted that the continued use of fossil fuels is unsustainable due to the environmental impact of CO₂ emissions on global warming. In 2007, the International Panel on Climate Change (IPCC) reported that an 80% cut in greenhouse gases was needed from developed countries to limit the future damage, and European politicians have committed to achieve this by 2050.

At present, transport represents a third of total CO₂ emissions in the UK and, over the last decade, has increased faster than any other sector. It is evident that an overall reduction of 80% will not be achieved unless there are significant reductions in emissions from transport (RAE, 2010). In the next 5 years this is likely to be achieved through improved efficiency of new cars, increased take up of new model hybrids, vehicle charging infrastructure initiatives, and introduction of early market ultra-low carbon vehicles.

In response to these commercial and legislative factors, both Original Equipment Manufacturer (OEM) partners involved in LCVTP intend to include low carbon vehicles within their product line-up in the near future. These vehicles will present a range of new and unfamiliar technologies to the driver, and it will be vital for automotive manufacturers to make the driver’s interaction experience with the HMI a positive and rewarding part of the overall LCV ownership experience.

In order to remain competitive, automotive manufacturers are constantly searching for ways to improve the customer's opinion of their vehicles. In the last five to ten years, the role of technology in cars has steadily expanded beyond the familiar areas of safety and efficiency features, to include entertainment, communication, and information services. The underlying purpose of many of these technologies is to enhance the driving experience, and make vehicles that are 'fun' to own. Increasingly, a vital driver of customer acceptance and satisfaction is the quality of the user experience when interacting with these technologies. The point at which a user interacts with the technology is known as the Human Machine Interface (HMI); this provides a way for the user to manipulate the system and for the system to indicate the effect of the manipulation. Because of this key position mediating between user and machine, the experience of interacting with the HMI needs to be a positive one, which is why automotive manufacturers and suppliers wish to optimise this aspect of their vehicles (Mauter and Katzki, 2003; Snook, 2008).

"HMI and driver information in EVs [electric vehicles] is the new frontier that automobile designers should have their hands on"  J.Mays, Ford Vice President of Global Design (Automotive Design, 2010)

The adoption of LCVs will introduce many unfamiliar issues for the user such as novel starting/stoping procedures, or communicating the effect that driving style has on the potential mileage range. For example, when starting a hybrid vehicle, power is coming from the battery and electric motor, and the driver does not receive the same auditory or tactile feedback that they would from an internal combustion engine. This has could lead to confusion over the state in which the vehicle is in, or worse, have safety implications. These unknowns mean it is vital to understand the related HMI issues as these will have an impact on the user interface requirements.

To this end, it is necessary to consider the HMI from a user-centred perspective. Specifically, this means understanding the interaction between the driver/passenger and the LCV, and then designing the user interface to maximise usability, satisfaction and enjoyment.

1.2. Research scope and objectives

The high level objective for this project has been to gather information related to the use of low carbon vehicle HMI from actual users. The project sets out:

To identify the key HMI concerns and appropriate solutions specific to users of Low Carbon Vehicles
To satisfy this objective, the project is therefore taking a user-centred approach to investigate the behaviour, needs, and opinions of LCV users. This is being conducted over three separate tasks, and this report comprises the findings from the first of these. It encompasses analyses of mainly secondary data sources including user blogs, published research, news articles, and road tests. Tasks two and three will gather primary data from questionnaires, interviews, and user trials.

From the variety of available LCV vehicle types, the project is considering non-commercial Hybrid electric vehicles (HEV), Plug-in Hybrid Electric Vehicles (PHEV), Range Extending Electric Vehicles (REEV), and Full Electric Vehicles (FEV).

The term Human-Machine Interface covers a wide selection of controls in a modern passenger car, and in order to focus the research, certain controls have not been considered. Specifically, issues concerning the pedals, steering wheel, door handles, and seat controls have been omitted. It is known that the brake feel of regenerative systems in LCVs is important to users; however it is beyond the scope of this project.

As noted in the introduction, due to the unique nature of many LCV technologies, drivers have to interact with a range of initially unfamiliar technologies. In order to understand the issues people have when using them, and provide guidance to designers and engineers, the following questions will be addressed:

- **What are the market trends in LCV telematics and HMI, and what solutions are available on current and near term vehicles?**

- **What learning from persuasive and eco-feedback research can be applied to LCV design?**

- **What are the most important HMI related issues and behaviours that LCV users experience?**

1.3. Profiles of hybrid and EV drivers

In the US, hybrid vehicle owners in general are wealthy, older, educated, active, and overwhelmingly democratic in political affiliation - the classic early adopters of new technologies. They have a much higher income than the average car buyer, with 42 percent having an income of greater than $100,000 - more than twice the national average. Their average age is closer to 50 rather than the average age of 40, and they are more than twice as likely as all U.S. adults to have a college degree. In fact, 27 percent have a post graduate degree, compared to nine percent of adults overall.

From a lifestyle perspective, hybrid owners are more technically savvy than average; are twice as likely to go skiing, hiking, or practice yoga than non-hybrid owners; and consume more organic food than the general population (Hybrid Cars, 2006; Scarborough Research, 2007).

The demographics of EV owners unsurprisingly show them to be early adopters, and very similar to hybrid owners. The overwhelming majority of EV users (internationally and in the UK) are fairly young multi-car families with off-street parking, and with higher than average household income (around $120k in the US). They are environmentally sensitive, and with above average education; in the U.S. they are concerned about their country’s dependency on foreign oil and are politically active. Most of these owners already drive a hybrid, with the Toyota Prius, Honda Civic, Insight and Accord most common. (Deloitte, 2010; Inside Line, 2010; Slater et al., 2009).
2. Automotive HMI within Low Carbon Vehicles

2.1. Market trends

2.1.1. Telematics

In the next 5 years the role that telecommunications and rich information play in the LCV user experience is set to increase markedly. Telematics features such as integrated Global Positioning System (GPS) technology, mobile communications, and navigation systems are set to become commonplace. Market assessments for in LCVs show a trend towards standardising telematics and associated HMI, and by 2015, more than 80% of electric vehicles sold globally will have standard telematics features (up from approximately 50% in 2010) (Frost & Sullivan, 2009).

The benefits of telematics advances will be greatest to FEV drivers, largely due to the anxiety associated with running out of charge, and the whole charging process. Range anxiety is regarded as a major challenge that needs to be resolved if mass adoption of EVs is to happen, and drivers will need more than simply a map showing reachable charging stations. It should be noted however that there is evidence range anxiety reduces with length of car ownership (see section 4). While in-vehicle applications such as advanced navigation systems, and integration of mobile phones are seen as perks for most drivers, they may well become essential for drivers of electric cars.

One of the key areas in the development of the ‘connected car’ is the provision of points of interest (POI) information to the driver. In particular, dynamic POI information such as availability and booking of charging stations will be crucial to help reduce range anxiety for EV drivers. Figure 1 shows which key telematics features are forecast to be required in upcoming EVs; the majority of which will require some kind of HMI.

In addition to POI services, smartphone and web applications will provide remote access to a great deal of information about their vehicle, and enable the user to accomplish tasks like manage the charging process, and pre-condition the interior using the climate system.

2.1.2. HMI

As vehicles have become increasingly complex, more and more features (and therefore displays and controls) have been added to both entertain the vehicle occupants and to support the driver in carrying out the primary driving task. This drive for additional features is jointly due to Original Equipment Manufacturers (OEMs) looking for a competitive edge over their competitors, and consumers demanding access to far more information.

Typically, driver related automotive HMI consists of the following elements:

- Primary driving controls (steering wheel, pedals, shifter). Note: these types of HMI are not being considered within this report.
- Instrument cluster
- Displays / controls associated with supporting the primary driving task (e.g. Navigation)
- Supplementary displays associated with the primary driving task (e.g. head-up display, blind spot monitoring)

(just-auto, 2010)

**Instrument Clusters**

Instrument clusters have traditionally consisted of two primary dials (speedometer and tachometer), often supplemented with minor dials such as fuel level and engine temperature, and an LCD message display area. Over the last 5 years however, executive vehicles have seen the introduction of reconfigurable LCD displays as an addition to, or replacement for analogue dials. These displays are capable of displaying several different layers (i.e. configurations) of real-time information in full-colour, with the configuration changing to reflect the relevant information at that point in time. This ability to convey the relative importance of information through size, colour, transparency, shape, or motion offers flexible design opportunities to make key information comprehensible, and improve driver safety.

For OEMs, reconfigurable displays also offer an opportunity to add value in a way that is difficult for competitors to duplicate. By optimising the look, feel, and usability of the displays, and by overlaying user interfaces with brand-specific cues it may be possible to relate the (hopefully good) user experience with their brand for the customer (Sawyer, 2008). Future instrument clusters are likely to feature more customisable dials and gauges, displaying more information on what’s going on around the vehicle; over time this technology will inevitably trickle down to become common in mass market vehicles.

Figure 2 shows the full TFT LCD instrument cluster used in the 2010 Range Rover. It allows the speedometer to ‘slide’ to the right when in off-road mode, to allow for additional information to be displayed. The Jaguar XJ (2010) uses the same technology, whereas the Mercedes S Class (see Figure 3) uses a combination of LCD screen for the speedometer, plus physical dials. In this case, the screen can also be used to display a night vision image. The recently launched Chevrolet Volt REEV also has a 7" reconfigurable cluster display.

**Supporting and supplementary displays**

With increasing demand for driver-focused display ‘real-estate’, Suppliers are noticing a trend towards larger, higher resolution displays being used in the instrument cluster and the central display. OEM’s are having to carefully consider the information split between the instrument cluster, head-up display, rear-view mirror and other displays shared with the front passenger.

The automotive design trend is for more spacious, uncluttered interiors. Touchscreen technologies such as resistive, capacitive, and projected capacitive offer space saving
opportunities by reducing the number of hard buttons. This, combined with their increased use within consumer electronics devices, may well lead to an increase in their use in automotive HMI. It is likely that touchscreen use will be supported by the introduction of haptic feedback when pressing the on-screen buttons. This interaction technology is similar to that already seen on some current touchscreen smartphones.

The uptake of head-up displays (HUDs) has seen a steady increase since their introduction by General Motors in 1988, with a recent escalation since Corvette’s colour head-up display in 2001. OEMs such as General Motors, Saab, BMW, Honda, Toyota, Lexus, Citroen, Peugeot and Nissan all offer head-up displays as an option fit on their vehicles, and they are likely to be available on even more vehicles in the future.

**Voice**
The use of voice recognition, particularly as part of a multimodal HMI will increase, complemented by simplified (smarter) voice instructions and better recognition rates.

**Workload Managers**
The introduction of more features into the vehicle inevitably means more information that can be displayed to the driver. Increasingly, the impact of this on vehicle safety is being considered by vehicle OEMs.

Volvo introduced the ‘Intelligent Driver Information System’ (IDIS) in 2006 to manage the presentation of information to the driver when the driving situation is deemed cognitively demanding. By using indicators like vehicle speed, steering wheel angle, and throttle input for example, an incoming phone call can be delayed, or certain input functions disabled. It is anticipated that similar systems will be introduced by other OEMs as suppliers such as Delphi and Motorola are currently researching such systems.

**Consumer Electronic Devices**
The fast pace of development within the consumer electronics industry, and the increasing focus on the user experience by brands like Apple is changing consumers’ expectations about automotive HMI. Consumers want to continue to use the electronic devices they have at home in their vehicle, and are expecting to seamlessly integrate these devices through protocols including Bluetooth and Wi-Fi. This brings a number of challenges for automotive manufacturers, not least that that these devices’ HMI generally do not meet automotive HMI guidelines.

Consumer devices are increasingly using touchscreen displays and, related to that, is the use of gestures (e.g. finger swiping and multi-touch zooming). In time, the use of gestures will be seen in automotive HMI (which will impact on the touchscreen technology used).

### 2.2. Competitor HMI benchmarking

This section reviews the HMI specific to LCVs that currently exists in the market, or is being demonstrated on near-term concept vehicles.

Table 1 provides a summary of the HMI content within 34 existing low carbon vehicles. The content is primarily located within the instrument cluster. The table shows known content only.

#### 2.2.1. Power in/out gauge

**Power in/out gauge**
The majority of low carbon vehicles have some form of power in/out gauge. This is a gauge which shows energy being used (for example, when the vehicle is accelerating) or energy recovered through regenerative braking. Some vehicles also have a power in/out gauge in addition to an RPM gauge.

Where they are present, virtually all of the displays are analogue with over 70% using familiar needle and dial displays see Figure 4). In general, from resting needle position, clockwise needle movement indicates energy being used, and anticlockwise needle movement indicates energy being recovered. Some, like the BMW Active E concept only show power being used, closely mirroring the function of an rpm gauge. There are however some examples of alternative displays being employed such as the moving dots in the Nissan Leaf.

Digital displays that give exact values provide some advantages such as quicker reading times and fewer errors in readings, but analogue displays can enable the user to make a quick qualitative assessment (e.g. I am regenerating energy), and easily convey the difference between current and target values (‘check reading’). Many users prefer the simplicity of analogue dials as illustrated in...
Table 1: Summary of known HMI content within a subset of current Low Carbon Vehicles

| Vehicle                  | Type       | Power | Power | Digital or | RPM | Modified? | Hybrid | Battery | Digital or | Ready | Cluster | Central | Consump | Eco- | Charging | Charging |
|--------------------------|------------|-------|-------|-----------|-----|-----------|--------|---------|-----------|-------|---------|---------|---------|      | feedback | port location |
| Audi Q5 Hybrid           | Hybrid     | x     | %     | A         | x   | A         | x      | x       | x         |       |         |         |         |      |          |             |
| BMW X6 Hybrid (2010)     | Hybrid     | x     |       | A         | x   | A         | x      | x       | x         |       |         |         |         |      |          |             |
| Chevrolet Tahoe (2010)   | Hybrid     | x     | None  | A         | x   | Auto-stop | x      |         | x         |       |         |         |         |      |          |             |
| Chrysler Aspen Hybrid    | Hybrid     | x     | None  | A         | x   |           | x      | x       | x         |       |         |         |         |      |          |             |
| Ford Fusion (2010)       | Hybrid     | x     | None  | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Honda Insight (2010)     | Hybrid     | x     | None  | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Hyundai Sonata (2011)    | Hybrid     | x     | None  | A         | x   |           | x      | x       | x         |       |         |         |         |      |          |             |
| Lexus CT200h (2011)      | Hybrid     | x     | None  | A         | x   |           | x      | x       | x         |       |         |         |         |      |          |             |
| Lexus GS450h (2007)      | Hybrid     | x     | KW    | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Lexus HS250h (2010)      | Hybrid     | x     | None  | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Lexus L560h (2008)       | Hybrid     | x     | None  | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Lexus RX450h (2010)      | Hybrid     | x     | None  | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Mercedes ML350 (2010, demo)   | Hybrid     | x     | %     | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Mercedes ML450 Hybrid (2010) | Hybrid   | x     | %     | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Mercedes S400 Bus Hybrid | Hybrid     | x     |       | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Peugeot 3008 (2010)      | Hybrid     | x     | %     | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Porsche Cayenne (2011)   | Hybrid     | x     |       | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Toyota Camry (2010)      | Hybrid     | x     | KW    | A         | x   |           | x      | x       | x         |       |         |         |         |      |          |             |
| Toyota Highlander (2011) | Hybrid     | x     | None  | A         | x   | Auto-stop | x      | x       | x         |       |         |         |         |      |          |             |
| Toyota Prius Gen 2 (2004)| Hybrid     | x     | None  | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Toyota Prius Gen 4 (2006) | Hybrid   | x     | None  | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Chevrolet Volt (2011)    | PHEV       | x     |       | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Ford Escape (2008)       | PHEV       | x     | None  | A         | x   | EV position| x      | x       | x         | x     |         |         |         |      |          |             |
| BMW Concept ActiveE      | EV         | x     | %     | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Honda Fit                | EV         | x     | None  | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| MINI (2009)              | EV         | x     |       | A & D     | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Mitsubishi i-Miev (2009) | EV         | x     | None  | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Nissan Leaf (2010)       | EV         | x     | None  | D         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Peugeot iOn              | EV         | x     | None  | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Smart EV (2010)          | EV         | x     | KW    | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Suzuki Swift (Technology demo) | EV       | x     | None  | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Tata Vista               | EV         | x     |       | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Tesla Roadster (2008)    | EV         | x     | KW    | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |
| Think City (2010)        | EV         | x     | None  | A         | x   |           | x      | x       | x         | x     |         |         |         |      |          |             |

Table 1: Summary of known HMI content within a subset of current Low Carbon Vehicles
the following comment by a journalist reviewing the new Chevrolet Volt REEV:

My only beef with the car is the speedometer is a digital number rather than an “analogue-like” needle depiction, which to me is easier to convey speed by merely scanning angle position rather than “reading” a number (DeMeis, 2010).

and also by a number of members of the gm-volt.com website

With all those neat screens, could I get some analog-style dials for speed and rpm? RPM is kind of gimmicky since there’s not different gears, but I’d really prefer a needle dial for speed, not a number [...] I’d sure like a dial for mph (Lyle, 2010 comment 13)

In general, the question of whether digital is better than analogue depends on the type of information to be displayed and the nature of the task being carried out. In complex real-world environments, the need for check readings, evaluation of future states and other factors related to ‘situation awareness’ can override simple considerations of speed and accuracy of quantitative readouts (Anderson and White, 2009).
2.2.2. Battery state of charge indicator

Most low carbon vehicles include a battery state of charge (SoC) indicator within their HMI. This is especially important for FEVs as once the charge depletes, there is no auxiliary power source. This indicator is either a permanent display or is driver selectable.

Compared with power in/out gauges, OEMs are using a wider variety of ways of representing the information. Although many displays use digital technology, often the actual information is displayed in an analogue manner (as opposed to a numerical value). Common solutions include needle and dial, and various graphic representations of bars in a battery similar to a mobile phone or laptop (see Figure 5). Some displays combine SoC information with estimated range values which enables the driver to get a more comprehensive understanding of these related concepts.

Surprisingly, not all displays indicate a ‘low charge’ amount, and where it does appear there is no apparent consensus as to what level constitutes ‘low charge’. This is a cause of confusion for some drivers, as comments in the ‘user feedback’ section illustrate. A suggestion here is to base the low charge threshold on the mean daily mileage data from the various LCV trials reviewed in section 4.2. This would equate to approximately 26 miles for the current European EV market.

Figure 5: Battery state of charge displays in LCVs
2.2.3. Range information

The estimated distance that your vehicle can travel on the current battery charge or fuel level is a critical piece of driver information, and especially so for FEV owners. It is predominantly communicated numerically, and is often combined with the vehicle’s SoC information, as can be seen in Figure 5 and Figure 6. Combining analogue and digital information enables the driver to get an approximate understanding of the current state with a quick glance, as well as the more exact figure in miles or km (providing this figure is accurate).

Additionally the Nissan Leaf integrates POI information within the navigation system to show the available charging stations within your range.

Figure 6: Displays showing estimated vehicle range
### 2.2.4. Power flow displays

In an attempt to educate new hybrid owners of the vehicle state and the way the technology works, a number of OEMs have incorporated a power flow diagram into the HMI. Typically this is shown in a central display; however in some vehicles the information is simplified and shown within the instrument cluster (Figure 7).

OEM research shows that users report that the usefulness of the information presented reduces the longer they own the vehicle. This may be because the power flow information is not regarded as essential to the operation of the vehicle, and once the novelty has worn off, drivers become less interested in it. These displays may therefore be more of a marketing tool that an effective way to improve driving efficiency. In the Ford SmartGauge display however, this information is represented by an indicator needle that shows when you are about to change from electric to combustion engine power. In this case, users do find this informative as it enables them to temper their driving style and remain in EV mode (see section 3.2.1 for more details).
2.2.5. ‘READY’ indication

A common user issue for hybrid vehicles is knowing when the vehicle is in a state that it can be driven (as a result of a lack of audible feedback normally provided by the internal combustion engine starting).

To address this issue some LCVs provide 'Ready' feedback to the user when the vehicle is started (Figure 8). This feedback is either a 'Ready' message appearing in the cluster, a gauge pointer moving to a 'Ready' position (BMW), or alternative audible feedback (Nissan Leaf).

Feedback from users suggests that when the subtle 'Ready' message is only textual, this is often missed. In the Audi cluster this is supplemented with needle movement as well.

2.2.6. Charging feedback

Plug-in hybrids and full electric vehicles require charging via mains power. This is a novel task to most users as it is not required with internal combustion engine powered vehicles. A number of plug-in low carbon vehicles provide feedback when the charging connector is properly connected and the hybrid battery is being charged (Figure 9). Some also supplement this with feedback on the state of charge level. Given the novel nature of the task, and its importance to the basic operation of the vehicle, this HMI is seen as a necessity. To successfully supply feedback on the charging process it will be necessary to understanding what feedback should be provided, and where this information is provided to the user.
2.2.7. Extended navigation features

Some OEMs have introduced, or are planning to introduce novel telematics features for LCVs. Locating and booking charging stations is likely to be a key function demanded by EV customers as highlighted by Frost & Sullivan (2010). Both Nissan and BMW have integrated these Points of Interest into the vehicles’ navigation systems (see Figure 10).

In the ‘MyFord Touch Eco-Route’ system (Figure 11), the basic navigation system has been supplemented by a feature that uses historical and real-time traffic data to calculate the fastest, shortest, and most fuel-efficient ways to reach a destination.

Typically, Eco-Route charts a course that avoids congested freeways while maximizing the use of major roads where the driver can maintain an efficient rate of speed. Ford of Europe engineers claim improvements in fuel economy of up to 15%. The system also offers up a bar chart next to the fuel display that shows real-time fuel economy performance along with mpg averages for the past 5, 10, and 30 minutes.
2.2.8. Remote information

Several OEMs are developing LCV specific smartphone apps to enhance the ownership experience of electric vehicles by providing additional functions which can be accessed remotely. The most common functions available on current systems are monitoring the SoC, giving the available vehicle range, monitoring and controlling the charging progress, and pre-conditioning the interior by controlling the climate control system. A matrix of available functions on current applications is shown in Table 2, with screen shots in Figure 12.

The GM OnStar system available for the Chevrolet Volt (Figure 12) is currently the most comprehensive smartphone application, and has the following functionality:

- Displays charge status – plugged in or not, and voltage (120V or 240V)
- Provides flexibility to “Charge Now” or schedule charge timing
- Displays percentage of battery charge level, electric and total ranges
- Allows owner to manually set grid-friendly charge mode for off-peak times when electricity rates are lowest
- Sends text or email notifications for charge reminders, interruptions and full charge
- Displays miles per gallon, electric only miles, and odometer readings
- Shows miles per gallon, EV miles and miles driven for last trip and lifetime
- Remotely start the vehicle to pre-condition the interior temperature

Figure 12: Smartphone applications show information about the vehicle and allows control of some functions remotely. (top: Chevrolet Volt, bottom: BMW ActiveE, and MyFord Mobile)

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Vehicle type</th>
<th>Battery SOC</th>
<th>EV Range</th>
<th>Total Range</th>
<th>Monitor charging progress</th>
<th>Notification of completed charge</th>
<th>Notification of charge interruption reminder to plug-in charging (immediate / delayed)</th>
<th>Remote start</th>
<th>Locate charging stations</th>
<th>Interior pre-conditioning before charging</th>
<th>Non hybrid specific features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chevrolet Tahoe (2010)</td>
<td>Hybrid</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mercedes ML350d (2010, diesel)</td>
<td>Hybrid</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mercedes ML350 Hybrid (2010)</td>
<td>Hybrid</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mercedes S400 BlueHybrid</td>
<td>Hybrid</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Chevrolet Volt (2011)</td>
<td>PHEV</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>BMW Concept ActiveE</td>
<td>EV</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Honda Fit</td>
<td>EV</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td>Nissan Leaf (2010)</td>
<td>EV</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Peugeot iOn (2011)</td>
<td>EV</td>
<td>x</td>
<td>x</td>
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<td>x</td>
<td></td>
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<td></td>
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<tr>
<td>Smart EV (2010)</td>
<td>EV</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td>Think City (2010)</td>
<td>EV</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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</table>
2.3. Summary

The next 5 years is going to see a substantial increase in the prevalence of telematics and associated HMI in LCVs. This will be particularly evident in FEVs where the integration of navigation systems with Global Positioning System (GPS) technology, and mobile communications will be needed to help users manage the whole charging process.

From an HMI perspective, one of the major trends is the introduction of configurable displays, particularly in the instrument cluster. These will allow contextual information to be shown that is relevant to the task in hand, as well as providing greater design flexibility from a visual and brand perspective.

This flexibility should be managed sensitively as it will be easy to confuse, or overload the driver with unfamiliar interfaces. A case in point is the choice of whether to display key information such as speed, in an analogue or digital (numerical) format. Research shows that users find analogue displays easier to interpret, as often they only wish to compare their current state with a target state, rather than know an exact value. In certain situations such as understanding available range/SoC, an optimal solution may be to combine numerical and analogue information.

Currently, there is no clear consensus on a design paradigm for SoC displays; needle and dial, and graphic representations of bars in a battery similar to a mobile phone are equally common. Surprisingly, not all displays indicate a ‘low charge’ amount, and where it does appear there is not agreement on what level constitutes ‘low charge’. This is a cause of confusion for some drivers. It is suggested that the low charge threshold is based on user data such as the mean daily mileage FEV drivers undertake (approximately 26 miles in European FEV trials).

Although Power flow displays are common in hybrid vehicles, there is a danger they will become regarded as little more than gimmicks as more people become familiar with how the technology works. They do however offer the potential to educate drivers as to how their driving style influences the operation of the vehicle (and hence their efficiency), as witnessed in Ford’s SmartGauge. This probably requires a move towards a simpler visualisation of the information that can be linked to a goal such as ‘remaining in EV mode’.

One of the greatest areas of innovation for OEMs is likely to be the development of smartphone applications that allow remote monitoring and control of vehicle functions. These are already starting to be seen, and from an LCV perspective the most common functions are being able to monitor the SoC, see the available vehicle range, monitor and control the charging progress, and pre-condition the interior by controlling the climate control system.
3. Persuasive and eco-feedback technologies

The rapid mainstream adoption of powerful mobile computing devices, together with advances in sensing systems are enabling a new class of interfaces to be created that motivate behaviour change by providing well-timed information to users at points of decision, behaviour, or consequence. Known as persuasive and eco-feedback technologies, these are technologies that are designed to change attitudes or behaviours of users through persuasion and social influence, without resorting to coercion (Fogg, 2003).

As environmental issues such as climate change, air pollution, and water scarcity become more prominent in the global consciousness, they have increasingly become active targets of research. A popular form of environmental psychology, and human computer interaction (HCI) research is the design and study of eco-feedback technology which can be seen as an extension of persuasive technology. This technology is based on the idea that most people lack awareness and understanding about the impact that their everyday behaviours such as driving, showering, or using air conditioning have on the environment. To aid understanding and encourage behaviour change, technology may be used to automatically sense these activities and feed related information back to the user through computerized means such as mobile phones, digital and ambient displays, or online visualizations (Froehlich et al., 2010).

Numerous studies have demonstrated the beneficial effects on behaviour that eco-feedback can provide, particularly in regard to reducing energy and resource consumption. An extensive review of empirical research to ascertain which kinds of feedback are most effective in helping users control their electricity consumption found reductions of between 5% and 12% (Fischer, 2008). This is similar to the reductions cited by Darby (2006), where savings of 5% to 15% were attributed to direct feedback (i.e. information available in real time on a display monitor).

In a review of driving studies, Fairchild (2009) cites reductions in fuel consumption in the order of 6% to 15% due to eco-friendly driving, depending on the type of vehicle used, and initial skill of the driver; in the Netherlands, energy-efficient driving training as part of their government run Ecodriving scheme has resulted in average efficiency improvements of 10% (UK Energy Research Centre, 2006). A study by Honda found that drivers using their Eco Assist system (fitted to their Insight Hybrid cars) improved fuel economy by an average of 10%, with the potential for 20% improvements after 300 drives (Lucas, 2010).

Within the category of home energy management systems, it is forecast that there will be 28.1 million users worldwide of energy information displays (EIDs) by 2015. Of these, in-home display devices will be the largest category, with 14.4 million units, followed by web-based dashboards with 11.1 million users, and mobile phone energy applications with 2.6 million users (Pike Research, 2009).

The proliferation of these displays, coupled with associated media campaigns will mean many consumers will soon be accustomed to interpreting the eco-feedback information they provide, and modifying their behaviour to reduce energy consumption. The authors believe this familiarity presents an important opportunity for introducing similar technology into cars in order to reduce carbon emissions. Indeed, this is already beginning to be exploited by some automotive manufacturers as discussed in section 3.2.1.

3.1. Design strategies for persuasive technologies

Underlying the design of such technologies should be a sound understanding of the theoretical foundations of human behaviour and people’s motivation for change. Extensive work has already been conducted in the field of environmental psychology, with rational choice, norm activation models, goal-setting theory and the transtheoretical model of behaviour change considered relevant to the design of persuasive technology. Although a comprehensive review of this research is beyond the scope of this report, it should be noted that much of this work is relevant to the design of persuasive technologies.
The model of environmentally relevant behaviour shown in Figure 13 (Matthies, 2005 cited Fischer, 2008) combines much of the previously mentioned theory into a high level scheme, and is useful in explaining why and how feedback can reduce energy consumption.

In the model, environmentally detrimental habits are those activities that are performed regularly without being reflected upon, for example using air conditioning at low engine speeds increases fuel consumption. The conscious decisions in the upper parts of the model are those decisions needed to break the habits.

Initially, the person must realise there is a problem, and that their behaviour is relevant to the problem. Then they must become aware that they have the ability to influence their behaviour and solve the problem. Following this reflection, a person enters into a process of weighing up and evaluating different motives in order to reach a decision on how to act. Considerable information is necessary in order to carry out the decision process; a person must know about the nature of the problem, the existing options and their respective consequences, in order to judge them in terms of norms and motives. This is where interface design, and the feedback it provides is crucial to successful behaviour change.

Beyond this theory, it is important to consider how these technologies impact upon, and integrate into the user’s everyday life. It is likely that such products will be used in various circumstances in both personal and work life, and thus the social implications of their use is vital to acceptance of the technology (Consolvo et al., 2009). For example, it may be that some drivers of cars such as SUVs may not wish their fuel consumption habits to be publically visible (e.g. on a website, or ‘always-on’ instrument display) due to differing social judgements related to the environmental friendliness of such vehicles. If this is the case, their wishes should be respected. On the other hand, being able to boast about your ‘eco-credentials’ by having a visible indication of your efforts may be socially desirable for some, and therefore should be supported.

3.1.1. Strategies for motivating pro-environmental behaviour

Designers must recognise that lifestyle behaviour change is a long-term endeavour that pervades many aspects of everyday life, and a principled approach to design is therefore needed. The following strategies from behavioural and environmental psychology represent those that are popularly used to influence pro-environmental behaviour.

**Goal setting**

Goal setting operates through a comparison of the present and a desirable future situation. In a summary of 35 years of empirical research on goal-setting, Locke and Latham (2002) found that goals affect behaviour primarily through four mechanisms:

1. Goals serve a directive function—they direct attention and effort toward goal-relevant activities;
2. Goals have an energizing function and, in particular, high goals often lead to greater effort than low goals;
3. Goals affect persistence
4. Goals affect behaviour indirectly as individuals use, apply, and/or learn strategies or knowledge to best accomplish the goal at hand.
When goal-setting is combined with feedback this is a valuable technique to stimulate environmentally responsible behaviour. Different studies investigating electricity and gas usage have found reductions of 12-15% when employing this strategy (Froehlich et al., 2010).

Feedback
Studies investigating the effect of feedback on domestic energy consumption show that clear, instantaneous, and direct feedback is necessary for consumers to learn how to control usage. People may however need additional help in interpreting the information and deciding what course of action to take (Darby, 2006). To make the displays more user friendly it was also recommended to show expenditure and historic usage information.

Fischer (2008), in her review of the effects of feedback on household electricity consumption, identifies the following key features as effective in stimulating conservation and giving user satisfaction. The feedback:

- Is based on actual consumption (i.e. accurate and trustworthy)
- Is frequent (ideally, daily or more often)
- Involves interaction and choice for households
- Involves appliance Comparison
A comparison between individuals, groups, or self-comparison can be useful in motivating action, particularly when combined with feedback about performance. The effectiveness of such social comparisons is not universally acknowledged however, and some research within environmental psychology has shown that while people are often interested in comparisons, they do not necessarily have an impact on their behaviour. Countering this is the popularity of forums specifically catering for users of current hybrid vehicles such as the Toyota Prius, where drivers compare fuel economy figures and 'compete' for the highest miles per gallon.

Commitment
Making a commitment to behave in a certain way, or achieve a certain goal increases the probability that the behaviour will be followed.

Incentive and rewards
Incentives have been used effectively to motivate a range of pro-environmental consumer behaviours from investments in home insulation to rebates for new energy-efficient home appliances. The incentives do not have to be monetary however; conferred status or convenience has also been found to be motivating. In fact sometimes, just an acknowledgement of positive behaviour is enough, as shown by Consolvo et al. (2006) in a small study of a prototype mobile phone application intended to encourage physical activity. An '*' was used to indicate that the user met her activity goal, and this was positively commented on; with some surprise considering how small the incentive was.

Communicating information
Media campaigns, websites, and leaflets are one of the most common means of promoting pro-environmental behaviour change. In order to maximise their effectiveness, they must be easy to understand, trusted, presented in a way that attracts attention and is remembered, and delivered as close as possible—in time and place—to the relevant choice.

The following eight design strategies (Consolvo et al., 2009) are a development of persuasive technology design goals initially proposed by Jafarinaimi et al. (2005). The strategies additionally include concepts from behavioural and social psychology theory, and have been validated through field trials of the UbiFit Garden system described in section 3.2.

1 Abstract & Reflective. Use data abstraction, rather than raw or explicit data collected from the user and any technologies, to display information to encourage the user to reflect on his/her behaviours by showing the user what s/he has done and how those behaviours relate to his/her goal.

2 Unobtrusive. Present and collect data in an unobtrusive manner, and make it available when and where the user needs it, without unnecessarily interrupting his/her everyday life or calling attention to him/her.

3 Public. Present and collect the data, which is personal in nature, such that the user is comfortable in the event that others may intentionally or otherwise become aware of it. Because the data needs to be available whenever and wherever the user needs it, it is likely to be something that s/he wears/carries, resides in a shared/common space, or uses while in the pres-
ence of others. The technology should not make the user uncomfortable in those situations.

4 Aesthetic. If the display and any accompanying devices function as a personal object(s) that may be used over time, they need to be inquisitive and sustain interest. The physical and virtual aspects of the technology must be comfortable and attractive to support the user’s personal style.

5 Positive. Use positive reinforcement to encourage change. Reward the user for performing the desired behaviour and attaining his/her goal. When the desired behaviour is not performed, the user should not receive a reward nor a punishment, but his/her interest should be sustained.

6 Controllable. When appropriate, permit the user to add to, edit, delete, and otherwise manipulate data so that it reflects the behaviours that s/he deems suitable. The user should be in control of who has access to what aspects of his/her data.

7 Trending / Historical. Provide reasonable and accessible information about the user's past behaviour as it relates to his/her goals. Historical data should accommodate changes in lifestyle goals over time and provide for the portability of data across devices.

8 Comprehensive. Account for the range of behaviours that contribute to the user's desired lifestyle; do not artificially limit data collection and representation to the specific behaviours that the technology can sense or monitor.

3.2. Eco-feedback interfaces

UbiGreen
The UbiGreen project was carried out in conjunction with Intel; it is a prototype mobile application that uses sensors and self-reporting to monitor transportation activities and provides feedback to the user to encourage green transportation habits. Green transport refers to any eco-friendly alternative to driving alone. The designs were tested in a 3 week field trial with 13 individuals, 72% of whom stated they would be willing to set goals for themselves to travel in a more eco-friendly way. (Froehlich et al., 2009).

In a pre-study survey, participants did not state a strong preference for iconic (50%) or numeric (47%) representations. Iconic representations used an abstract image or metaphor to indicate green behaviour in some way, whereas numeric representations used text or a bar graph. The researchers decided to test iconic designs as shown in Figure 14.

In the ‘growing tree’ interface, at the start of each week, the tree is almost bare. Leaves, blossoms, and eventually apples are progressively added to the tree after each green transportation event. The alternative interface shows a polar bear on a small iceberg. Over the week, the iceberg grows as green transportation actions are taken and the surrounding ecosystem also improves with fish and seals appearing. The last image in the sequence provides a small, but engaging final reward. In the tree design, the flowers give way to fruit and in the polar bear design, the sun sets and the Aurora Borealis (Northern Lights) appears. The images never return to a previous state due

![Figure 14](image.png)
to inactivity, but at the start of each week, the interface is reset to the first image in the sequence.

**UbiFit Garden system**
The UbiFit Garden project was also carried out in conjunction with Intel, and attempts to encourage regular physical activity through the use of on-body sensing, and mobile displays. To motivate the user, a garden blooms on the screen background of an individual's mobile phone as she performs physical activities throughout the week (see Figure 15). At a glance, the user can determine if they are having an active or inactive week (by the number of flowers), if they have incorporated variety into their routine (by the types of flowers), and if they have met their activity goals this week and in recent weeks (by the appearance of large and small butterflies). An interactive application on the phone includes more detailed information about the individual's physical activities, and allows the user to manually add, edit, and delete information about their activities. In field trials, this facility was considered essential as it allowed the user to correct mistakes made when inferring activities, thus ensuring credit was correctly given for all activity undertaken (Consolvo et al., 2009).

![Figure 15: UbiGarden mobile display indicating successful goal attainment and level of physical activity over a week](image)

Results from field trials showed that the system was effective in encouraging physical activity. When the display was always visible as wallpaper on the phone, participants maintained their physical activity level over time, while for participants without the ‘always visible’ display, their level of physical activity dropped significantly (Consolvo et al., 2008).

### 3.2.1. Automotive applications

Some low carbon vehicles include real-time or historical feedback on driving style with the aim of encouraging the driver to drive in a more environmentally friendly way. The most common examples of this are graphical displays of consumption and energy recovery data as pioneered by Toyota on the Prius, and subsequently on Lexus hybrids.

Examples of these displays are shown in Figure 16. Rates of consumption in mpg are typically recorded over a limited time period of 15 or 30 minutes, and update every minute. Extra information in the form of recovered energy from regenerative braking and acceleration is sometimes overlaid, as can be seen on the Garmin ecoRoute HD, Mercedes ML350h, and Lexus displays. The Garmin product also gives driving tips on how to improve your efficiency score and save on fuel costs.

This information is typically available for review whilst driving, although being able to digest this quantity of information such that a change in driving behaviour can be effected may cause distraction and limit their influence. Having said that however, some Prius owners have been able to achieve 60-70 miles to the gallon by following their displays.

> **When I bought my hybrid – it was the visual interface on the touchscreen that really encouraged me to watch my acceleration – not just in the obvious situations, but also during freeway driving where I can visually watch my success, mile-age-wise on downhill coasts and speeding up before an uphill stretch – lessening the amount of gas I need to add to get over the rise** (Lyle, 2010 comment 160).

Most of the hybrid vehicles with this consumption feedback also have power flow diagrams within the same interface - the ‘Energy’ button visible in the Prius and Lexus’ screens display the power flow graphic (see section 2.2.4 for more information).

Some OEMs are also making driving efficiency feedback available on websites. The Fiat eco:Drive system (Figure 17), allows the user to analyse consumption and emission data from previous journeys, and gives advice and tutorials to help you drive more efficiently.

Such websites allow drivers to interrogate the information in greater depth, and without the risk of distraction whilst driving. They do not however provide the immediate feedback needed to easily relate driving behaviour to efficiency goals, and should probably be viewed as supplementary to in-car guidance. One good feature of the Fiat website is the way that eco-behaviour is communicated in
monetary terms; i.e. projected savings. This mirrors the wishes of participants in trials of home energy displays (Anderson and White, 2009).

As a comparison, Figure 18 shows the information available from Google’s PowerMeter tool. This energy monitoring tool allows you to view your home’s energy consumption online on your personal iGoogle web page. It uses energy information provided by utility smart meters and energy monitoring devices and is able to provide near-real-time information so you can see the direct effects of any changes you make to your electricity usage. Like the Fiat tool, energy usage is given in different units including money.

Recent HMI developments by OEMs have advanced the concept of eco-feedback with more explicit attempts to educate the driver and persuade them to drive more efficiently. In general, these interfaces incorporate an indication of efficiency that requires less information to be digested compared with consumption graphs. The feedback is made available when and where the user needs it (usually in the instrument cluster), without unnecessarily interrupting their driving. This characteristic adheres to the second design strategy recommended by Consolvo et al. (2009), and described in the preceding section.

In my opinion GM got it right with the ball since it’s in the instrument pod where your eyes can scan it by habit – not turning one’s head to the center display and further away from the road up ahead (Lyle, 2010 comment 173).

Importantly, the driving efficiency information tends to be portrayed in either an abstract or metaphorical manner which makes it easy for drivers to understand how their actions relate to the goal of greater efficiency (design strategy no. 1: Consolvo et al., 2009). Figure 19 shows examples of these interfaces. Graphical solutions include trees, leaves, or vines that “grow” or evolve as the driving style becomes more environmentally responsible. In the Chevrolet Volt, there is an orb that rises or falls to reflect smoothness of braking and acceleration; the goal is to keep it in
the centre of the gauge which helps focus effort on driving efficiently. Similarly, with the metaphor of growing plants there is a clear goal, and it encourages changing your driving style by giving only positive feedback; i.e. more leaves are seen as a reward for driving in an environmentally responsible manner (design strategy no. 5: Consolvo et al., 2009). This is backed up by some forum posts where a dislike for negative feedback was stated:

*I was countered by some who said they didn’t want to be reminded of how bad their driving habits were* (Lyle, 2010 comment 176)

Other implementations include a colour change within the cluster as seen in the Honda Insight. People who have driven vehicles fitted with the Ford SmartGauge are very positive about the experience, and despite the amount of available information, find it simple to understand, and a useful aid to driving efficiently:

*The real-time feedback it provides is very helpful in achieving optimum fuel economy* (Bell, 2009).

*Not exactly informative but none the less rewarding is the green leafy vine that grows on the right hand side of the gauges* (Merva, 2009).

Aside from being visually pleasing SmartGauge is extraordinarily useful. The LCD screens show exactly the information you need to drive Fusion Hybrid to its fullest. We especially appreciated the “PWR” gauge, which adapts as the vehicle changes between electric-only and hybrid-gas modes. As throttle is applied the power line moves up accordingly. While in electric-only mode, part of the gauge is shaded green, giving visual representation to how close or far away you are from kicking on the gas engine or returning to electric-only power... Not just a cool toy - Ford’s SmartGauge is a tool for the driver that delivers massive benefit (Merva, 2009).

Some vehicles also give additional assistance to the driver in the form of alternative information on their energy usage. In the Chevrolet Volt, the central display provides the driver with information about his or her energy usage by showing how their driving style and climate control choices affected energy use (Figure 20). There is also a link which gives tips on how to improve your efficiency - although the tutorial is not interactive, it is simply a legend for the various dash screen items. A different screen shows the energy usage and miles per gallon used since the last charge. Here the numerical mpg value is
visually subservient, but complimentary to the analogue portrayal of economy (Lyle, 2010). This again makes it easier for the driver to visualise their goal.

Amongst people who are interested in the Volt, or who have driven it there is concern that the interfaces may be over-complicated for certain drivers. The following quotes suggest that early adopters - or in their own terms, ‘geeks’ - are keen on all the information available, and will make good use of it, however there will be a separate group of customers who will be daunted by the complexity. If this issue is not managed carefully, the potential of the eco-feedback to improve efficiency may be lost on a large proportion of the mainstream users. This risk is also identified by Anderson and White (2009) in their user-study of energy information displays. They make the point that careful specification of the default mode of a display is critical in order to cater for those who are scared of interactivity.

There is an issue with information overload... Personally, I love toys, so I liked the complex setting. But even the simple one has a lot of information, and some people may be daunted (EricR, 2010).

That’s a pretty intimidating amount of information being displayed. I’m a computer/software engineer so you’d think I would like all that info display and control but I’m afraid this may be going too far from what people are used to. I’m thinking that my Mom would be overwhelmed by it all (Lyle, 2010 comment 4).

Being the geek in the family, I love these data screens and would probably play with them at the stoplight – if it never got me into trouble dawdling at the green light, that is…. That said, my wife would leave the thing on one screen and never check any ancillary screens, just as she does our current hybrid (Lyle, 2010 comment 30).

I agree that there is the potential for information overload, but I figure that GM will pick a set of sensible default screens that most people will use. Beyond that, some of the more interested parties might dabble with various other screens. since it is a new technology, some of the stuff is oriented toward helping you to figure out how to drive in a more energy-efficient manner. I’m all for that because I think too few people tend to think that way. however, even with the available data, I suspect that many drivers still won’t think in terms of energy efficient driving (although I don’t expect such drivers to be among the early purchasers of the volt) (Lyle, 2010 comment 40).
In the Honda Eco Assist system, there is a driver-selected ECON button that automatically helps increase fuel efficiency by engaging the idle stop feature sooner; operating air conditioning more in recirculation mode; reducing the automatic climate control fan blower speed; optimising throttle angle input; and limiting power and torque by around four per cent.

3.2.2. Home energy information displays

There has already been considerable research carried out into domestic energy use, and ways to help people manage their consumption. As mentioned at the start of this section, home energy monitors and information displays are becoming much more commonplace, and lessons can be learned from their design.

At the most basic level, energy monitors provide a simple readout of the total amount of energy the home is using. They may also show additional information such as the monetary cost of the electricity consumed, or may let users monitor energy usage by day or time, or appliance.

In a user study of energy information displays amongst a group of UK consumers (Anderson and White, 2009), 7 commercially available products were evaluated to provide evidence of what display features are likely to be most effective at encouraging behavioural change, and to establish ‘best practice’ in terms of energy display design.

The following design principles are derived from the study (n.b. only principles relevant to automotive applications have been included):

1. Changing values are poorly served by numeric displays. Although participants valued the accuracy of numbers, they also recognised that a changing rate is better expressed as an analogue indicator.

2. Keep it simple. Moves to add features or functionality were always countered by the many participants who wanted to prioritise simplicity.

3. A rate explained is complex; a rate experienced is intuitive. Initially participants struggle with the concept of a rate, especially a rate of spend, and how to communicate it, but their experience of using the displays rate dispelled these problems. The meaning of a rate of spend is quickly grasped in practice.

4. Everyone understands money. Watts, kilowatts and especially kilowatt-hours will never be universally understood or accepted as units of energy consumption. Money offers a straightforward alternative for both rate of consumption and historic consumption.

5. Interactivity is lost on those who are scared of losing what they have gained. Interactivity may be important for those who are keen to maximise the value of their displays but there will always be individuals who do not want to interact with the display for fear of losing the screen that they understand. Careful specification of the default mode of a display is therefore critical.
Different users have similar needs. Different people do want different things from their displays but there is a core of information and functionality desired by everyone.

The geo Minim (Figure 21) was the most popular out of 7 tested (scoring an average of 9.4 out of 10), and providing the functionality that consumers identify as being critical. It focuses on the cost of energy use, but power consumption in KW and carbon impact in kg CO2 is also available. Several different time periods are available for historical usage (today/yesterday/last 7 complete days/last 30 complete days). In terms of display design, psychological literature points to the importance of achieving a balance between digital (numeric) information and analogue information and also between simplicity and extended functionality. This unit achieved a good balance and users thought that the ‘speedometer’ display was visually clear and drew attention to the reading. They also found the target bar a useful ‘quick glance’ visual.

Figure 21: geo Minim smart energy meter

3.3. Summary

User interfaces or products that motivate behaviour change by providing well-timed information to users at points of decision, behaviour, or consequence are known as persuasive technologies. Within these are eco-feedback products which specifically aim to encourage pro-environmental behaviour change such as driving more efficiently.

Numerous studies have demonstrated the beneficial effects on behaviour that eco-feedback can provide, particularly in regard to reducing energy and resource consumption. When applied to driving, fuel savings in the order of 6% to 15% can be achieved. The introduction of such technology is already beginning to be exploited by some automotive manufacturers, and it is very likely this will become commonplace. For those OEMs that implement these systems well, this offers an opportunity to provide real benefits to users.

Much research has already been conducted in the fields of Environmental Psychology, and Human Computer Interaction, and this provides a firm theoretical base on which to design applications for LCVs. Popular strategies to encourage behaviour change include goal setting, feedback of relevant information to the user, performance comparison between individuals and groups, or self-comparison, and provision of incentives (material or psychological). Combining goal-setting with feedback has proved to be a particularly effective strategy.

From a design perspective, the relevant data should be portrayed in an abstract or metaphorical manner, rather than giving the raw or explicit data. This makes it easy for drivers to understand how their actions relate to the goal of greater efficiency. Examples of this include trees, leaves, or vines that “grow” or evolve as the driving style becomes more environmentally responsible, or an orb that rises or falls to reflect smoothness of braking and acceleration.

The data should also be presented in an unobtrusive manner, and made available when and where the user needs it, without unnecessarily interrupting his/her everyday life. In cars, this is generally achieved by displaying the feedback in the instrument cluster.

By using positive rather than negative reinforcement to encourage change, the user is rewarded for performing the desired behaviour and attaining his/her goal. Users do
not like being chastised for driving inefficiently, and this will not motivate them to try harder.

Information about the user’s past behaviour or performance as it relates to his/her goals should be accessible. Currently this is achieved through historical consumption graphs in the central display; however consideration must be given as to whether this solution is overly complex for mainstream LCV drivers. Potentially, digesting this quantity of information whilst driving, such that a change in driving behaviour can be effected may cause distraction.

The automotive interfaces that have most successfully applied these principles are the Ford SmartGauge as found in the Fusion hybrid, and the LCD screens in the Chevrolet Volt. User feedback regarding the SmartGauge has been largely positive with drivers finding it rewarding, and useful in helping maximise fuel economy.
4. User issues

4.1. Sources of the user data

In order to understand how people use LCVs, and the issues they have, a range of data from different sources was analysed. This comprised blogs from drivers of low carbon vehicles, news articles, road tests and reviews, and published research from field trials.

In order to include responses from drivers of several different vehicles, a number of blogs were analysed. These included personal blogs of participants in the US Mini E trial which ran from June 2009-June 2010; a blog by a UK family called Boxwell, who trialled the Reva G-Wiz and the Mitsubishi iMiEV electric cars between 2006 and present, and a blog by a Californian electric car enthusiast called Kodama who has owned a GM EV1 in the late 1990s, a Toyota RAV4 since 2003 and has taken part in the recent BMW Mini E trials.

106 news items related to low carbon vehicles, dated 1st-16th November 2010 were identified using the search engine GoogleAlert. Of these, only six mentioned HMI issues. In addition, several motoring journalists have reported on their experiences of using low carbon vehicles. Peter Curran travelled 4500 miles around Europe in a Think City electric car, writing about his journey in The Daily Mail (Curran 2010); and Lanning (2008) wrote about his experiences of using a Smart Fortwo Electric Drive.

There have been a number of field trials involving LCVs in recent years and many of these have published publicly available findings. Their objectives are largely similar: to study real world use of LCVs, by gathering objective usage data such as charging patterns and daily mileage, together with subjective data about the users’ experiences of living with the vehicles.

The following trials were reviewed:

The CABLED project in the West Midlands, UK. This 12 month trial has reported the findings from 22 Mitsubishi iMiEV drivers and is still on-going (Aston University, 2010a, 2010b).

Mini E trials in the USA, Germany, and UK. The first trial commenced in the USA in 2009, and the second six month trial in the UK is still ongoing. All the others have completed. In total, approximately 600 people will have taken part.

UC Davis PHEV trials. The Davis University in California conducted research related to PHEV use, with 34 participating households trialling adapted Toyota Prius vehicles (Kurani et al. 2009).

The CENEX Smart Move Trial in the North East of England. The Centre of Excellence for Low Carbon and Fuel Cell Technologies conducted a six month study considering the feasibility of integrating Smart Fortwo Electric Drive cars into fleets (Carroll, 2010).

Those data which met the inclusion criterion of mentioning HMI or user-interaction issues were analysed thematically (Braun and Clarke 2006). Taken across the various data sources, the most common themes found were range anxiety, issues connected with the charging process, user feedback and behavioural adaptation when driving LCVs. These will be discussed in more detail in the following sections.

4.2. Range Anxiety

Range anxiety is the term given when drivers experience anxiety about their car’s ability to cover the distance required before it needed to be recharged. It occurs almost exclusively in drivers of FEVs because the limited charging infrastructure means they cannot easily ‘refill’, unlike with petrol or diesel fuelled vehicles. This issue had two clear aspects to it: firstly, inexperienced drivers describing their concern about running out of charge; and secondly, more experienced users reporting that their anxiety had reduced as they had become used to their vehicle. Some drivers reported that their anxiety increased because they could not trust the feedback that they obtained from the vehicle, and this is explored in section 4.4.
4.2.1. Users’ concern about running out of charge

The stressful nature of range anxiety is clear from the emotive language used to describe it;

“I have to admit, it wasn’t fun… I had that feeling at the pit of my stomach that you get when you know something bad is about to happen and you can’t stop it. I got lucky and made it [home]…” (Maloughney 2009a)

“I saw the electricity light come on and tell me I had 10 miles left. I panicked!! …OK. Here come the nerves and tears again…” (Graham 2010).

Lanning (2008) found that the time and planning needed to charge the vehicle effectively made him nervous about being able to manage any unplanned trips;

“You also struggle with any unplanned journeys. For instance, at night, with no power left and the car charging, you suddenly have to take your child to hospital? At least with a hybrid you have the conventional fuel system to help you out.”

According to the Office for National Statistics (ONS), the average private daily mileage across the UK for conventional vehicles is 22.8 miles, compared to 22.4 miles in Germany for average daily car use in cities, and approximately 40 miles for US drivers as a whole. Table 3 shows daily mileage statistics from a number of EV trials. It can be seen that apart from the USA Mini E trial, EV users are driving almost exactly the same distances each day as similar non-EV drivers. Figure 22 illustrates the typical skewed distribution shape for daily mileage in which approximately 68% daily mileage is less than 45 miles (±1 standard deviation).

With more experience however, daily distances increase and range anxiety decreases. This can be seen in the daily mileage increase from 22.9 miles to 25.1 miles over 3 months for CABLED trial participants (Table 2), and in blog entries. Around 50 miles seems to be an initial ‘rule of thumb’ distance commonly cited in both blogs and other research as the trigger point for range anxiety. Woody (2010) described the best cities for electric vehicle use, based on the assumption that most drivers do not experience range anxiety when driving distances of 50 miles or less;

“The conclusion from new research by General Electric and Deloitte based on the assumption that the best markets for electric cars are cities with a high percentage of drivers whose daily commute is 50 miles or less. That happens to be the ideal distance that electric car owners can go without suffering from “range anxiety” that they’ll drain their batteries before they can recharge.”

4.2.2. Range anxiety reducing with experience

There is considerable evidence that users’ anxiety decreases once they learn what the real range of their car is, and start to factor that in to their journey planning. The Boxwell’s blog reported how the family initially underestimated the range available from their Mitsubishi i MiEV;

“We estimated that the maximum we could achieve was around 50 miles. This did reduce..."
the use of the car for medium length journeys.” (Boxwell 2010a)

However blog entries less than a month later showed that the Boxwell’s became familiar with the true range capacity of the car, which was nearer 93 miles. They ensured that they kept within this and eliminated their anxiety by doing so:

“We always know how many miles we can achieve on the range, so we keep within this range.” (Boxwell 2010b)

Several other drivers also reported that their anxiety reduced with the experience of using their vehicle and finding it to be capable of covering the distances they required:

“Range Anxiety is completely GONE! 100 mile range is completely adequate for what I do in my regular daily routine!” (Cooper 230 2009).

The long term EV owner Kodama, did not mention range anxiety at all in his blog, which may reflect his experience and familiarity with his vehicle.

In two six month Mini E trials conducted in the Berlin metropolitan area (N = 40 in each), Cocron (2010) found that participants initially had considerable concerns about the limited range of the car (95-125 miles). After three months ownership, however, almost all the participants found the range of the EV was suitable for their daily routes and only a small percentage of trips could not be made due to restrictions such as range or low battery charge. Similarly, in the Smart Electric Drive UK trial carried out between 2008-2009, participants’ anxiety disappeared with extended use.

In contrast to their expectations and their very first experiences they get used to the range and learn that it is sufficient. According to this the confidence in range increases. When receiving the electric vehicle users feel uncertain about mileage but after using the car for a while, anxiety about mileage is gone. They learn to handle it and adjust their driving behaviour.” (Hoffman, 2010)

In the Cenex trial however, range anxiety was reported throughout the length of the trial (Carroll, 2010). Drivers tended to be overly-cautious about the distances they were willing to travel, and only 7% of journeys were undertaken when the battery was showing less than 50% of charge. This is probably a result of the short time participants spent with their cars. Over the 6 month trial 264 different people drove the 4 available Smart Fortwo EVs and it is likely that they did not have time to adapt to the nuances of living with an EV.

4.3. Issues with the charging process

The whole charging process is novel for many LCV drivers reviewed, and has generated a number of common issues. The principle issue is related to vehicles failing to charge, and the stress this causes. There is a strong case for providing better feedback of the charging progress, and some kind of fault diagnosis to users, as several drivers reported dissatisfaction with the information provided. Another irritation for users was the location of the charging socket, when it was on one side of the car, as this could be an inconvenience. There were also comments from the participants about how often they recharged their vehicle, and a wish for help in locating places to charge

4.3.1. Problems with charging

A number of people blogged about the position of the charging socket on their vehicles. In general, sockets that allowed charging from either side of the car were more convenient, and were preferred. To cope with the side socket on the Mini E one user even rigged up a custom system in his garage to get round the problem.

“I had to back the car into the driveway and plug the charger in through a window to get a charge. I can see why the EV1 had the charger plug in the front it would be a much more convenient location. I also put a towel over the wheel charger light, as it was a bit too noticeable otherwise” (Robert 2009b).

“To allow for charging either car without moving the cars around, we had to run the charging cord for the Mini-E above the cars. This
arrangement allows the Mini to be charged on either side of the garage, and relieves us from having to drag the very stiff and heavy charging cord around to the Mini’s charging port. It has the additional benefit of preventing a loose charging connector from ever hitting the floor and being damaged...EV designers, please note that the best place for a charging port on an EV is not where the fuel filler is normally placed on a gasoline car!” (Kodama 2009b)

The RAV 4 had a more conveniently located charging point, which meant that the car could be charged from either side;

“The charge port of the RAV4 is at the front, slightly offset to the right side of the car, making it almost unimportant as to which side of the car the charger is mounted in our garage (good design!)” (Kodama ca.2004a)

A more problematic issue encountered by quite a few participants was the unreliable charging process. Descriptions of users’ behaviour suggest that better feedback of the charging progress, or fault diagnosis is needed to alleviate charging stress.

“Ever since the muggy weather set into NJ it has been affecting the charging of my MINI E. The 110 cables yellow breaker box often pops, that means it sits for 10 or so minutes then tries again. It then pops a bit later, cycles to try again until it just gives up. Meanwhile I am getting very little to no charging. Sometimes this happens in the middle of the night and I wake up to just a 5% increase. So while the MINI E is charging I look for that blinking LED on the MINI E battery indicator to make sure its blinking, if not I then check the yellow box on the cable to see what it is doing. Then I do my little dance of re-plugging the cable in if it does not cycle, then I run out to the car to see how much I got or didn’t get….I find myself constantly checking that MINI E LED, just like we glance at the range or % indicator when we drive. My Wife has pointed out I’m obsessed…I find myself re-checking about every 15-30 mins…I call this CHARGE ANXIETY.” (My Mini E: Mini E EVangelist - #402 2009b).

Even though none of the vehicles covered in this research yet provide smartphone applications, one participant thought that a means of remotely monitoring the charge status and reminding users to recharge would be useful.

“I’d forgotten to plug it in the night before, this is only the second time I’ve forgotten to do this but it’s an annoying mistake. I was reading about
30

4.3.2. Frequency of charging

Kurani et al. (2009) reported research looking at the behaviours of PHEV drivers in the Californian study. Results from the first 34 households, which were selected because they were able to recharge a vehicle at home, indicate that on average, they will recharge a PHEV once a day, but that there was a variation across households.

On average the cars in the UK mini E trial were charged every two to three days. Two thirds of users charged their car three times a week or less while only six per cent charged daily (BMW Group, 2010).

One of the bloggers in the US Mini E trial reported how charging became a new ritual which had to be incorporated into daily life;

"I’m still on the 110 and my routine is to get plugged in before 7pm and I’ll be at 100% by the time I need to leave for work in the AM. A nightly ritual.... “ (My Mini E: Mini EVangelist - #402 2009b).

The Boxwell family described how they charged their car every 2-3 days, having an average daily journey time of 22 miles:

"Each morning when we get in our electric Mitsubishi i MiEV, it is fully charged and ready to go. One charge will normally last us 2-3 days, on average we are travelling 22 miles per day“ (Boxwell 2010d).

4.3.3. Locating a charging point

Although users felt strongly that public charging facilities for EVs were desirable and even essential, in the main they coped without these facilities, and most charging was carried out at home. The perceived difficulties of being able to charge away from home meant users felt restricted in the type of journeys they could embark on

As highlighted above however, BMW reported that for Mini E users, in reality these concerns only affected a small percentage of trips. One reason for this could be the resourcefulness of EV drivers in seeking out charging opportunities, or developing networks of helpful souls

"Electric cars can all be plugged into a domestic socket…we found most bemused hoteliers and campsite owners happy to help" (Curran 2010).

"Fortunately the MINI E community is charitable. The dealer, Morristown MINI, has always let me come in and get back up to 100% whenever I needed to and other Pioneers like #250 and ‘John’ have offered their wall chargers when I need them” (My Mini E: Mini Evangelist - #402 2009b).

In the Cenex trial (Genex 2010), a wide variety of ways of charging the vehicles were used, including dedicated recharging posts and normal plug sockets. A correlation was found between the amount vehicles were charged when not in use and the location of dedicated public charging points, with public organisations using public charging points able to charge up more frequently than other users.

4.4. User feedback

Feedback during driving is critical to driver understanding of low carbon driving. Many of the comments about feedback related to early use of the vehicles and getting used to them. The theme of feedback during driving
included unreliable information about range and charging. There were both positive and negative comments about the lack of engine noise. There were also suggestions about how the feedback could be improved.

### 4.4.1. Unreliable information about range and charging

A few drivers found that the feedback from the vehicle concerning range and charging status was not always reliable:

“As I began my journey, the charge meter went down much faster than I expected it to. After only 5 miles, with 26 miles to go, I was down to 16% which could take me about 20 miles. The problem with the charge meter is sometimes if you check your charge level when you just unplug, it may give you a slightly higher reading than what you really have ……” (Maloughney 2009a).

“After full charge the gauge was at 100% but readout only said 94 miles” (Roni 2009).

“When we left home the mileometer was showing 96 miles remaining. On arrival at Tamworth Castle the readout was showing 62 miles remaining. Although we had only travelled 27 miles the dial was showing that we had used 34 miles. We always find that the mileometer is only a guide and will reduce rapidly when first used.” (Boxwell 2010d)

One user would have preferred more detailed feedback from the RAV4 about the power left in the car batteries;

“Going into the red (bottom 10%) puts the car into “reduced performance” mode which limits the acceleration allowed. A turtle icon lights up if that happens — cute, perhaps, but I prefer having more real feedback such as an indicator of the current being drawn from the batteries to assist in driving conservatively for maximum range.” (Kodama ca.2004b)

This driver also found the ‘battery voltage indicator’ uninformative in terms of indicating the range capacity, though they did feel this gave a good indication of the point at which the batteries are wearing out;

“To the right of the “fuel gage” is a battery voltage indicator which in most cases is useless. Not only are the units not marked, but there is only one dividing mark (between the top green section and bottom yellow section) indicating the “too low” threshold, whatever that is. In normal use the needle is always up in the green section until you are near the bottom of the battery capacity. It does, however, turn out to be somewhat useful at the point where the batteries are becoming worn out (somewhere around 80,000 miles for us). With old batteries, accelerating will cause the battery voltage to drop. If the drop causes the needle to go into the yellow zone, the car will go into reduced performance mode and thereafter limit the allowable acceleration. The reduced performance mode will reset if the battery voltage is allowed to recover to some point into the green. Thus, by watching the voltage indicator while accelerating, we can avoid putting the car into reduced performance operation.” (Kodama ca.2004b)

### 4.4.2. Comments about the lack of engine noise

A few of the entries concerning feedback discussed the lack of engine noise;

“I knew of course that an electric car would be quieter than a gas car, but I really didn’t expect this. On the highway I notice it because I can keep the radio at a lower volume. In town, I notice sounds I never knew were there – kids in some nearby backyard, the idle chatter coming out of a restaurant, etc. It’s weird. Nice, but weird.” (Mini E 217 2009c)

Others pointed out the dangers that this posed;

“We have been driving a Mitsubishi i-MiEV for the past 8 months at any speed above 15 MPH there is enough wind and road noise to let people
know you are coming. Below 15 MPH this can be a different story, there have been a few occasions when I have driven into our road and the children are out playing and are not aware of our presence.” (Boxwell 2010e)

“Wow, this car is a killer. A few days ago I came upon a group of birds in the road and, since they did not hear me coming, I ran over two of them, yes, they died. Today, on the way to work, same thing, but with squirrels. One got away, the other, not so lucky. Maybe I should just drive down the street with my hand on the horn...” (Saunders 2009b)

Mullet (2010) wrote about the absence of noise associated with electric cars;

“They are virtually silent up to a speed of 25 km/h. The potential risk to pedestrians and other motorists is obvious.”

This article suggested that the movement of an electric car should have some sound associated with it.

The RAV4 EV ignition was designed with a ‘twist-and-spring back’ ignition key emulating that in a gasoline car. As there was no engine noise/vibration, the user felt there was no clear indication that the car had started up. Because the key mimics that in a conventional petrol car, users unfamiliar with EVs might wait for feedback from the engine (sound or vibration) to confirm the car was ready to go.

“The “ignition” system uses a normal key, which must be turned to the “ignition” point before springing back to the operating position. For an electric car, this seems to be an unnecessary emulation of a gasoline car since the only thing that happens is that some lights flash. In fact, at least once, it has confused a valet parking lot attendant who thought the car wasn’t starting.” (Kodama ca.2004b)

4.4.3. Suggestions for improvements to feedback

Some participants suggested ways in which feedback on the charging current could be improved;

“First I think the car could tell you the Amperage it’s drawing while charging on the display, as it is you just don’t know unless you click through a bunch of menus maybe 10 or so short and long clicks on the selector switch, a very clunky system. But more useful would be if the plug you connected the car to told the car what amperage to use, it seems to me a very simple thing to have a RFID chip in the plug that the car could read. While we are on the subject of the plugs, I don’t like the current ones MINI choose to use for this project, they have tiny wires inside of them that look like they could easily brake from heavy use, and I can’t see this as a good plug to use in a public place like a Mall as there is no locking mechanism. I can just imagine kids going down a line of EVs plugged in at a charging site and unplugging them all.” (Robert 2009a)

Another driver appreciated the power use display and thought it would assist him to drive economically;

“I did note that there was a power use display which should be useful for giving feedback for efficient driving.” (Kodama 2009a)

One participant described how better feedback would help drivers drive within the range of their vehicles;

“This brings up one of the biggest problems with an electric car, … your range anxiety can be really strong. I hope public charging stations, or range extended EV’s will solve this problem, I also think a intelligent GPS navigation system that would work with the car to tell you when to head home would be great.” (Robert 2009c)

Biggs (2010) wrote about the effect feedback from the Chevrolet Volt had on his driving behaviour;

“You connect to the car over OnStar using an iPhone app – and a central LCD screen for
Nav and infotainment. There's also a separate driver's screen that displays current driving stats including your range and a little floating "ball" that shows how efficiently you're driving...The ball rises and turns yellow when you're gunning the engine and floats serenely in space when you're driving like Mother Theresa. This actually encourages a more zen-like form of driving. In fact, I found myself being more careful and driving more slowly when the ball thing was on the dashboard.

The study carried out by the Davis University (Kurani et al 2009) made several recommendations related to the design of the vehicle instrumentation:

- The closer the information is to the point of interest and action (i.e. ‘in car’ rather than ‘at home’) the more likely it is that it will be used
- Simplicity in representation and interpretation is critical to driver understanding
- The interface should support drivers in setting and achieving goals by providing relevant summary information
- Instantaneous fuel economy can provide drivers with erroneous information especially during braking
- Whenever possible information should be presented in a grounded context so that drivers can quickly understand the relative impact of their behaviour

4.5. Adapting behaviour to promote low carbon driving

Mini E drivers reported ways in which they had adapted their driving behaviour. Strategies included selecting their route in order to optimise the range and reducing the use of secondary controls. Also, learning to control their vehicle by using the throttle instead of the brake.

4.5.1. Optimising range and reducing the use of secondary controls

A few drivers reported that they planned their journey to optimise the range of their vehicle;

“I decided to take an alternate route home, one that doesn’t have much highway driving as opposed to my usual route that is about 60% highway driving.” (Maloughney 2009b)

Curran (2010) described how he had reduced the speed at which he drove in order to conserve battery power, although that meant driving more slowly than other drivers on fast roads;

“German autobahn users will insist on driving aggressively close with garnish of hornblowing and light-flashing. I admit my slow progress might have been a contributory element to their annoyance, but I needed to prolong the life of the battery before the next charging point. The power level ticked down and knuckles whitened - but the warm welcome I received once off the autobahn came as regular relief.”

Drivers sometimes choose not to operate additional features, such as the radio, heating or electric windscreen wipers in order to save power;

“With 20 miles to go, I’d lost almost 30%, so I turned the heater off (a decision not without regret as it was 38 degrees outside). At about the halfway point, I was down to 15% – which is when I turned the radio off, leaving me alone in the cold and dark with no human contact. With 10 miles to go, I was under 8%, and resorted to turning my windshield wipers on and off manually…” (Mini E #217 2009c).

“The heater or air-conditioning was verboten [forbidden] on this trip, as they used too much battery power.”(Curran 2010)

4.5.2. One foot driving

Using the accelerator to slow a vehicle instead of the brake increases the range and is termed regenerative braking. In the Mini E the regenerative braking is integrated only with the accelerator pedal, with the brake remaining a hydraulic brake. This is in contrast to conventional vehicles and other LCVs such as the Toyota Prius where the
regenerative braking is integrated with both the accelerator pedal and the brake pedal. This requires a change in driving style as you cannot coast and this ‘one foot driving’ has proven to be very popular. In the US Mini E trial, 98% of Mini E drivers liked the regenerative braking on their vehicles (Lentz, 2010).

“I definitely attribute the ability to retain power from the regen braking...I really pay attention to it and regen whenever I can (as long as it is safe)....it really makes a difference in stretching out those miles.” (My Mini E: Mini E Evangelist - #402 2009a).

“One-pedal Driving— thanks to the magic of regenerative-braking, the accelerator now also acts as a decelerator, and that yields a kinda different, but kinda fun, way of driving. [But] you need to be heavier on the gas in this car than you would with a regular stick and a clutch.” (Mini E #217 2009b)

“The braking takes some getting used to but I'm getting better. Unless someone stops suddenly in front of you, you very rarely need to touch the actual brake pedal.” (Mini E field trial users blogs 2010)

Some drivers felt they had become more engaged with their driving behaviour as a result;

“I have to say, part of the fun has been in seeking out and optimizing my regeneration opportunities. Red traffic lights now hold a certain appeal to this electric car driver, and I get a bit of a grin whenever I see a downhill slope. One of the most interesting aspects of driving an electric car is the way you can manipulate your source of power.” (Mini E #217 2009a).

4.6. Summary

Range anxiety was the most serious concern for inexperienced drivers but decreased for experienced drivers. As users got used to their vehicles they reported finding that the range of their vehicle was sufficient for most of the journeys they took. There is considerable evidence that users’ anxiety decreases once they learn what the real range of their car is, and start to factor that in to their journey planning.

The principle issue concerned with charging is related to vehicles failing to charge, and the stress this causes. There is a strong case for providing better feedback of the charging progress, and some kind of fault diagnosis to users. Another irritation for users was the location of the charging socket, when it was on one side of the car, as this could be an inconvenience. One Mini E user even rigged up a custom system in his garage to get round the problem. Drivers reported getting into a routine to cope with the requirements for frequent recharging.

The theme of feedback included some reports of unreliable feedback about range and charging status and about the lack of engine noise. The theme of adapting behaviour included strategies for planning routes, and reducing the use of secondary controls such as climate systems to conserve energy. There was also considerable mention amongst Mini E drivers of the benefits of regenerative braking, and how ‘one foot’ driving can be used to extend the vehicles’ range. This aspect of driving the cars proved to be very popular once owners had got used to it.

It should be remembered that most of the data was collected from participants who had positive attitudes towards low carbon vehicles. They were willing to accept the range limitations and adapt their driving behaviour in order to use the vehicles effectively. It is not clear whether the general population would be as willing to make these behavioural changes. The results informed the design of the questionnaires which will be used in the next stage of the project. These will aim to find out whether the problems identified by participants in this stage of the study are also experienced by participants in subsequent stages and explore how these might be overcome.
5. Conclusions and recommendations

The literature and products reviewed in this report show that there are a number of issues that are important to users of current Low Carbon Vehicles (LCVs). Within this report, LCVs are defined as domestic Hybrid electric vehicles (HEV), Plug-in Hybrid Electric Vehicles (PHEV), Range Extending Electric Vehicles (REEV), and Full Electric Vehicles (FEV).

Market analysis of LCV telematics and HMI
The next 5 years is going to see a substantial increase in the prevalence of telematics and associated HMI in LCVs. This will be particularly evident in FEVs where the integration of navigation systems with Global Positioning System (GPS) technology, and mobile communications will be needed to help users manage the whole charging process.

The design flexibility of configurable instrument clusters will allow contextual information to be shown that is relevant to the task in hand. This will allow greater amounts of information to be displayed, whilst maintaining simplicity if managed carefully. Research shows that users find analogue displays easier to interpret than digital (i.e. numerical) displays, as they allow users to compare their current state with a target state, rather than know an exact value. Currently, there is no clear consensus on a design paradigm for State of Charge (SoC) displays; needle and dial, and graphic representations of bars in a battery similar to a mobile phone are equally common. In certain situations such as understanding available range/SoC, an optimal solution may be to combine numerical and analogue information.

Surprisingly, not all SoC displays indicate a 'low charge' amount, and this is a cause of confusion for some drivers. It is suggested that the low charge threshold is based on user data such as the mean daily mileage FEV drivers undertake (approximately 26 miles in European FEV trials)

Although Power flow displays are common in hybrid vehicles, there is a danger they will become regarded as little more than gimmicks as more people become familiar with how the technology works. They do however offer the potential to educate drivers as to how their driving style influences the operation of the vehicle (and hence their efficiency), as witnessed in Ford's SmartGauge. This probably requires a move towards a simpler visualisation of the information that can be linked to a goal such as 'remaining in EV mode'

A potential source of innovation for OEMs is likely to be the development of smartphone applications that allow remote monitoring and control of vehicle functions. These are already starting to be seen, and from an LCV perspective the most common functions are being able to monitor the SoC, see the available vehicle range, monitor and control the charging progress, and pre-condition the interior by controlling the climate control system.

Learning from persuasive and eco-feedback research can be applied to LCV design
Eco-feedback interfaces which specifically aim to encourage pro-environmental behaviour change such as driving more efficiently are starting to be introduced on LCVs, and are likely to become more commonplace. When applied within cars, fuel savings in the order of 6% to 15% can be achieved. For those OEMs that implement these systems well, this offers an opportunity to provide real benefits to users.

Popular strategies to encourage behaviour change include goal setting, feedback of relevant information to the user, performance comparison between individuals and groups, or self-comparison, and provision of incentives (e.g. money saved). Combining goal-setting with feedback has proved to be a particularly effective strategy.

There are certain design guidelines for eco-feedback interfaces that have been shown by research to be effective, and can be seen in novel automotive applications such as Ford's SmartGauge, and the Chevrolet Volt. User feedback regarding the SmartGauge has been largely positive with drivers finding it rewarding, and useful in helping maximise fuel economy:

- The relevant data should be portrayed in an abstract or metaphorical manner, rather than giving the raw or explicit data. This makes it easy for drivers to understand how their actions relate to the goal
of greater efficiency. Examples of this include trees, leaves, or vines that “grow” or evolve as the driving style becomes more environmentally responsible, or an orb that rises or falls to reflect smoothness of braking and acceleration.

- The data should also be presented in an unobtrusive manner, and made available when and where the user needs it, without unnecessarily interrupting his/her everyday life. In cars, this is generally achieved by displaying the feedback in the instrument cluster.

- By using positive rather than negative reinforcement to encourage change, the user is rewarded for performing the desired behaviour and attaining his/her goal. Users do not like being chastised for driving inefficiently, and this will not motivate them to try harder.

- Information about the user’s past behaviour or performance as it relates to his/her goals should be accessible. Currently this is achieved through historical consumption graphs in the central display; however consideration must be given as to whether this solution is overly complex for mainstream LCV drivers. Potentially, digesting this quantity of information whilst driving, such that a change in driving behaviour can be effected may cause distraction.

- The automotive interfaces that have most successfully applied these principles are the Ford SmartGauge as found in the Fusion hybrid, and the LCD screens in the Chevrolet Volt. User feedback regarding the SmartGauge has been largely positive with drivers finding it rewarding, and useful in helping maximise fuel economy.

**Important HMI related issues and behaviours that LCV users experience**

Analysis of user blogs, published research, news articles, and road tests has highlighted a number of common HMI related issues that users of LCVs experience. These are summarised in Table 4, together with the related design problems that OEMs need to consider when developing vehicles.

<table>
<thead>
<tr>
<th>Category</th>
<th>Issue</th>
<th>Design problems raised from the research findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range Anxiety</td>
<td>Range anxiety due to fear of running out of charge</td>
<td>What are the realistic HMI changes/new features that OEMs can implement in order to reduce range anxiety?</td>
</tr>
<tr>
<td></td>
<td>Range anxiety reducing with experience</td>
<td>What are the realistic HMI changes/new features that OEMs can introduce to ‘speed-up’ this reduction in range anxiety?</td>
</tr>
<tr>
<td>Charging</td>
<td>Problems with charging</td>
<td>What is the optimal HMI design for vehicle charging feedback? Location on the vehicle? What charging states? Feedback time-out?</td>
</tr>
<tr>
<td></td>
<td>Frequency of charging</td>
<td>What is the best way that the OEM can remind (but not nag) the user to charge the vehicle? E.g. Location of feedback, frequency of feedback, conditional feedback etc.</td>
</tr>
<tr>
<td></td>
<td>Location of charging point</td>
<td>What is the best way for the OEM to inform the driver of the location of charging points in the near vicinity? Map, smartphone etc? Is information ‘pushed’? What information should be given?</td>
</tr>
<tr>
<td>Feedback</td>
<td>Unreliable information about range and charging</td>
<td>What are the ‘HMI rules’ that any range or charging information should abide by in order to promote confidence in the data?</td>
</tr>
<tr>
<td></td>
<td>Lack of engine noise</td>
<td>What is the most appropriate method of compensating for the lack of engine noise as a form of driver feedback?</td>
</tr>
<tr>
<td>Adapting behaviour</td>
<td>Optimising range</td>
<td>n what way can drivers be encouraged to safely adapt their driving style or chosen routes, such that efficiency is improved?</td>
</tr>
<tr>
<td></td>
<td>One-foot driving</td>
<td>What are the implications (if any) of ‘one-foot driving’ on the design and engineering of the accelerator and braking pedals? It appears that the ability to drive using only one pedal is dependant on the severity of the regenerative braking</td>
</tr>
</tbody>
</table>
Overall, users' anxiety about their car's ability to cover the distance required given its current state of charge (range anxiety) was their most prominent concern. This anxiety was prevalent in inexperienced drivers, and unsurprisingly was almost exclusively related to FEVs as their range is quite limited compared to conventional cars or REEVs.

On average, current FEVs have a range of approximately 100 miles (160km). This is about four times the average daily mileage in conventional vehicles in Europe, and nearly three times that driven in the US. There is considerable evidence that once drivers became more experienced with their vehicles, range anxiety decreased as they learned more precisely how many miles a charge would last. They factored this into their journey planning, and became comfortable that the range was sufficient for most of the journeys they took. In some cases it disappeared completely as drivers adapted to using chargers away from home.

Although the concept of charging is not in itself unusual, the process of charging LCV's was unfamiliar to most new owners, and presented a number of problems. The principle issue encountered is related to vehicles failing to charge, and the stress this causes. There is a strong case for providing better feedback of the charging process, with some kind of fault diagnosis to users. Another irritation for users was the location of the charging socket when it was on one side of the car, as this could be an inconvenience. One Mini E user even rigged up a custom system in his garage to get round the problem.

One of the main issues related to feedback of information to the driver was that estimates of range was unreliable – particularly when environmental factors like weather, traffic or road types (highways or smaller roads) had a large influence. There were some similar concerns about the reliability of the SoC information. The lack of engine noise elicited a mixture of positive and negative opinions.

There were numerous examples of drivers adapting behaviour when living with LCVs, and these included strategies for planning routes, and reducing the use of secondary controls such as climate systems to conserve energy. Amongst Mini E drivers, they frequently talked about the benefits of regenerative braking, and how 'one foot' driving can be used to extend the vehicles' range. This aspect of driving the cars proved to be very popular once owners had got used to it.

The main issues just described and summarised in Table 4 will be investigated in more detail in the next phases of this project through interviews and questionnaires with participants in the West Midlands CABLED trial, and also with user trials focussing on those issues deemed of highest priority to the workstream partners.
6. References


