TIPSLab Report 006-003

Persuasive User Interfaces to match Plug-In Eletric Vehicle (PEV) charging to renewable availability and off-peak power demand

PART 1

Prepared for NRCan

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1. INTRODUCTION

The replacement of the current fleet of internal combustion engine vehicles for plug-in electric vehicles (PEVs) is argued to give rise to valuable opportunities towards reducing carbon emissions and overall environmental impact of this transportation mode (Williams et al., 2012). However, this assumption is dependent on the source of electricity used to charge the PEVs. The effort to reduce GHG emission, reduce cost and improve the efficiency of the electrical grid relies on the link between the renewable energy sources and the growing fleet of PEVs.

The main objective of the ECO EII project is to inform strategies to link emerging PEVs' charging in Canada to renewable electricity sources. Incentives, technology and informative interfaces can play a significant role in this connection. In this report we discuss the use of persuasive user interfaces which, through the provision of real-time feedback, could motivate users to charge their PEVs during favorable periods (i.e., out of peak hours and when renewables are online).

We argue that one important feature of PEVs is that charging stores electricity rather than using it in real-time. This means that users can make a conscious choice about when to draw electricity from the grid to charge their vehicles. Users' behaviour becomes, therefore, a key aspect to the alignment of PEV charging and renewable energy sources.

Another relevant feature about PEVs is the fact that these vehicles can easily surpass a home's non-PEV electric energy load (REVI, 2012). In the long term, PEVs are expected to account for a substantial share of the total electricity consumption in high deployment regions[1]. Although the projected deployment of PEVs for the next two decades appears to be modest in most countries (ITF 2012), PEVs could still add significantly to peak load if vehicle charging is not adequately managed.

The reason for the current concerns with the PEVs' impact on peak load is that commuters will likely recharge when they return home in the evening, at the same time interval that the typical daily peak in load occurs (Morgan, 2012). In order to modify this charging behaviour, two main strategies are commonly discussed in literature. Financial incentive, the first and most recurring strategy, is normally presented with the goal of shifting the charging period to the night, when the system load is typically much lower. A second strategy has also gained increasing attention as smart grid discussions progress: the option of giving the power utilities direct control over the time PEVs can or cannot charge[2]. These two strategies are referred to as Time of Use (TOU) pricing and Utility Controlled Charging (UCC), respectively.

The current project intends to investigate and propose an alternative to these strategies.

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1. "On the most optimistic assumptions about the commercialization of PEVs, in which PEVs displace virtually all conventional vehicles in the global fleet by 2050, PEVs could add over 20% to global electricity demand" (Morgan, 2012). This number can be even more significant in some countries. "For example, were Israel to achieve its goal of becoming the first nation in the world to commit to an all-electric car infrastructure, the additional electricity needs for PEVs would amount to about half of the country's electricity use based on current mobility levels and electricity use" (Morgan, 2012).
2. Typically this control is not exerted unrestrictedly; instead limits to the control are established.

Such alternative is expected to overcome the limitations of UCC and TOU, and/or to increase their efficiency when adopted complementarily. Definitions, limitations and potential improvement of those strategies are discussed in the next paragraphs.

UCC is described by Axsen, Bailey and Kamiya (2013) as follows:

> "The idea is that the electric utility (e.g. BC Hydro) or a third party could have direct control over the timing of PEV charging. The purpose of this control would be to: 1) improve the efficiency of the electrical grid (reduce costs), and/or 2) increase the uptake of intermittent, renewable sources of electricity by matching PEV charging to the timing of when renewable sources are available" (p. 50).

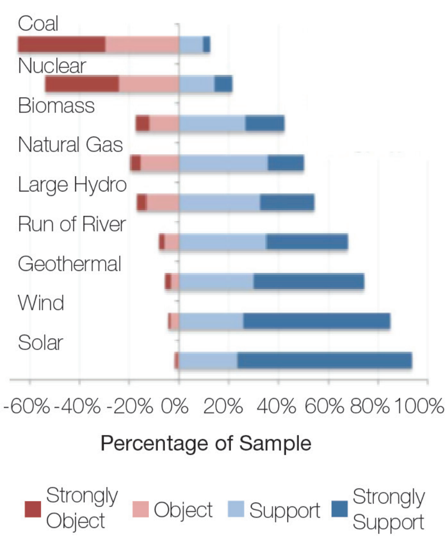


Figure 1. Respondent support for various sources of electricity (BC only, n = 442). Source: Axsen et al., 2013 (adapted).

The researchers conducted a survey to measure, among other things, UCC reception among potential PEV adopters in the province of British Columbia (B.C.). They found that potential PEV adopters in B.C. demonstrate interest in green electricity (figure 1), however results were less consensual when participants were asked about the idea of UCC (figure 2).

Although 69% of respondents believe that UCC could help the environment, they were mostly split when asked if UCC should be required for all Plug-in Electric Vehicles (PEV) owners. The survey also indicated that respondents are concerned with the expected loss of control and privacy related to the adoption of UCC.

However, user interfaces designed to provide the tools for PEV owners to make their own (informed) decisions and adapt their own behaviour, as proposed by this project, would secure both control and privacy for the users. This alternative is therefore expected to be more widely accepted, while also informing the population on the direct and indirect impacts of their actions.

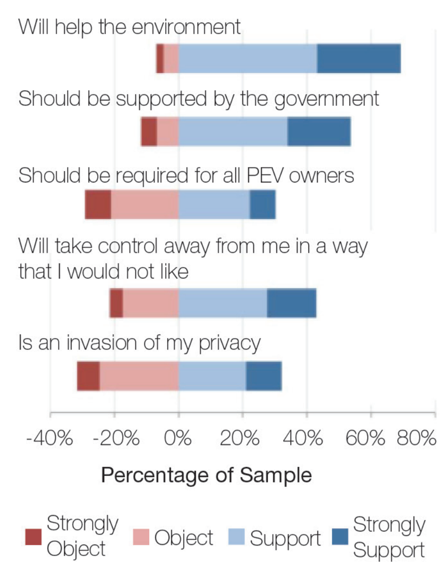


Figure 2. Perceptions on "Utility Controlled Charging" (BC only, n = 442). Source: Axsen et al., 2013 (adapted)

The second strategy, namely the adoption of Time of Use (TOU) rates, have proved to be effective in several regions in North America, as demonstrated by reports from Idaho National Laboratory's (INL) PEV Project. Figure 3 illustrates the profile of the estimated PEV fleet load in B.C. in the 15%, 50% and 100% PEV market penetration scenarios. This estimation, by TIPSLab, is derived from the average PEV fleet load profile reported by INL's PEV Project, as well as data on B.C's fleet numbers. The estimation considers scenarios with TOU rates in effect and without, which highlights this strategy's effectiveness.

However, a group of researchers suggest that money saving might not be the most effective incentive in the context of electricity management (Nolan et al., 2008; Schultz, 1999; Ayres & Shih, 2012). Other researchers have found that when coupled with assistive technologies, the effectiveness of TOU rates are remarkably amplified (Faruqui and Sergici, 2010).

It is also important to notice that unlike the efforts to shift charging periods away from load peak periods, the problem of aligning PEV charging with renewables may require means for provision of real time information. The reason is that the availability of electricity from renewable sources, especially from non-dispatchable plants, might not follow predictable patterns. While prescribing specific times as ideal charging periods (with favourable TOU pricing, for example) is an effective strategy for avoiding additions to load peak, this same strategy could hardly be reproduced for aligning PEV charging with renewables.

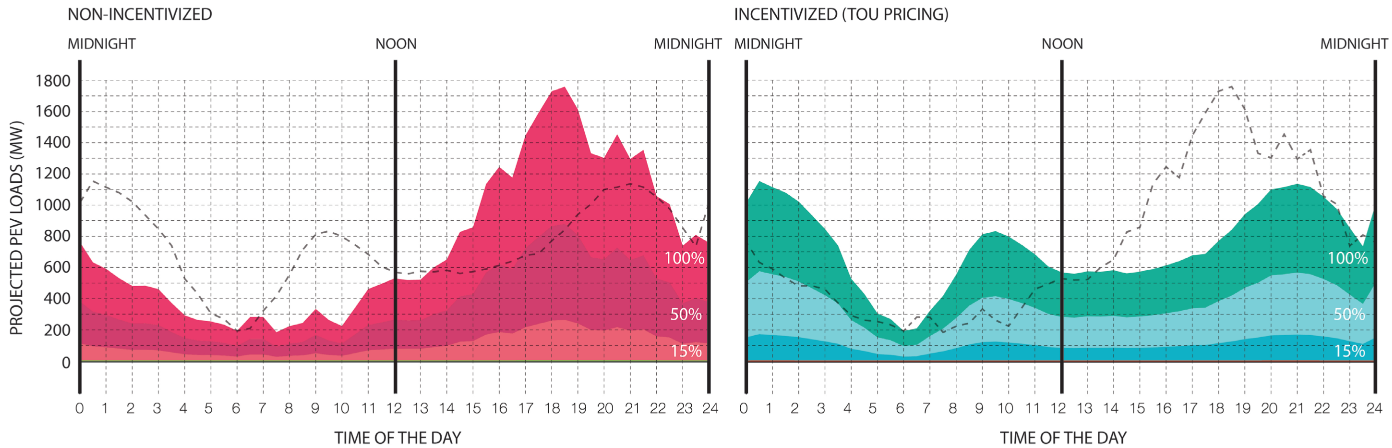


Figure 3. *Estimated PEV fleet load profiles for TOU incentivized areas (right) and non-incentivized areas (left) in B.C.* ***Source: TIPSLab*** *Report no. 006-002.*

This research project, therefore, intends to investigate other means to reinforce the charging time shift and to enable a more accurate alignment between charging events and the most beneficial charging periods. This will be achieved through the development of interfaces capable of providing timely information to the users on impacts and benefits (including financial incentives) of charge events in the most effective formats. The overall feedback model is described in Figure 4.

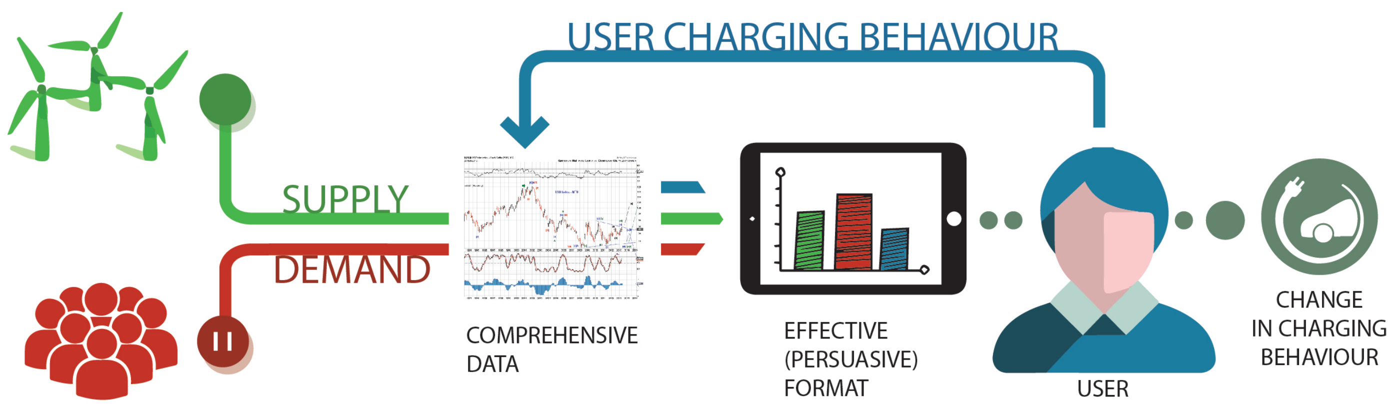
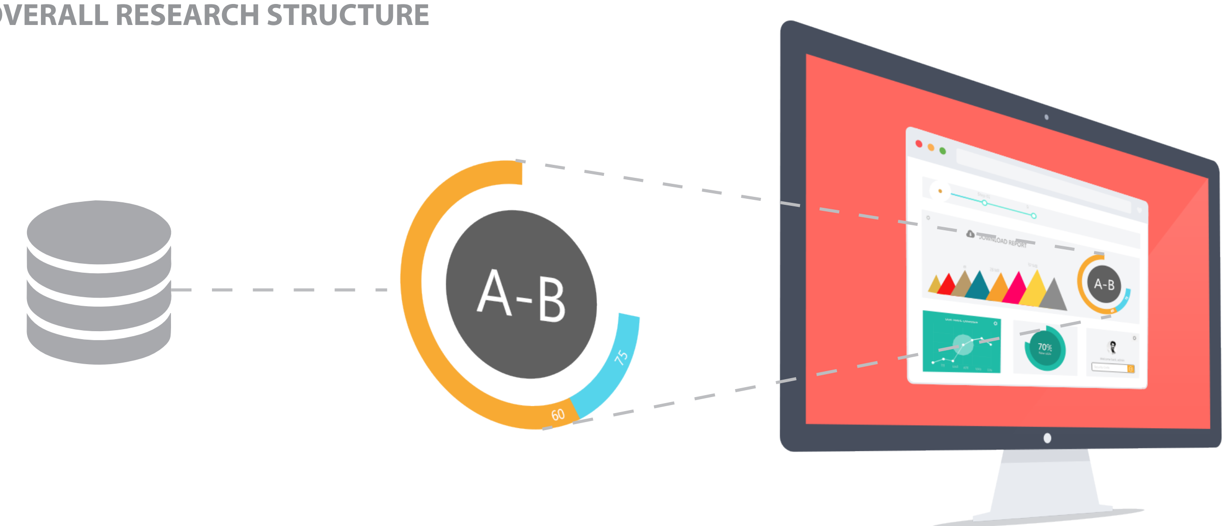


Figure 4. *Information components to feedback system*

The feedback model addresses two factors that define desirable charging periods, as previously discussed: (1) electricity demand, aiming at avoiding peak load, and (2) electricity supply, aiming at engaging with renewable supply. Additionally, the model includes feedback information on how users charge their vehicles in regard to such factors. This research will investigate the interfaces and/or design features that can effectively communicate such information, with focus on the use of persuasive approaches to motivate positive charging behaviour. This approach may be referred to as the “effective (persuasive) format” in which information is delivered to prompt action, including the means to deliver this information, i.e. the interface between data and user.

In order to develop interfaces able to achieve the goals stated above, several individual questions must be investigated a priori to inform the interface design. These different research questions and research foci are approached by different research projects that feed into the current project. The overall research structure is illustrated in Figure 5. The research stages presented with a dashed boarder are the ones conducted in this project.

OVERALL RESEARCH STRUCTURE



DATA
/raw content

TIPSLab Project 006-002

Analysis of historical data on electricity producton and consumption

Analysis of PEV charging profiles

Project TIPSLab 006-003

Application of historical data on forecasting ideal PEV charging periods in B.C.

Study of most adequate time and place for feedback information based on the PEV charging periods that must be incentivized

INFORMATION
/structured content

TIPSLab Project 006-001

Literature Review on motivation of pro-social behaviour in the context of PEV charging

Study on nudging positive PEV charging behaviour

- Experimental study on information approach and framing
- Experimental study on information visual elements

VEHICLE
/devices and interfaces

TIPSLab Project 006-003

Survey on existing PEV and energy management interfaces

Proposal of classification system for PEV charging feedback interfaces

- Study of estimated cost VS benefits for existing alternatives

Survey for identification of opportunities specific to BC's PEV potential adopters

- Technology adoption
- Perception on concept of feedback interfaces

FRAMEWORK
/interface guidelines

Project TIPSLab 006-003

Development of guidelines to support the conception of effective persuasive interfaces for PEV charging. Based on INFORMATION and VEHICLE research.

INTERFACES
/development and test

Project TIPSLab 006-003

Development of selected interfaces → Experimental study to test effectiveness of interfaces → Study on implementation for interfaces in BC

Figure 5. Research Structure summary

This report, TIPSLab Project 006-003, will summarize key aspects of projects 006-001 and 006-002, before moving to the development of framework and interfaces. All the stages covered in this report are organized in sections, as follows:

PART I - Clarifying the exploration space for potential PEV charging feedback systems

1. Introduction
2. Reviewing concepts: Feedback and Persuasive Technology
3. Situating the current project in the Energy Feedback landscape
4. Proposal of new categorization model for PEV charging feedback
5. Analysing and classifying interfaces for PEV charging feedback

PART II - Defining the context in which the interfaces to be developed will operate

6. The potential PEV adopter profile and derived opportunities
7. The energy scenario in British Columbia – TIPSLab report 006-002 summary
8. Making data effective – TIPSLab report 006-001 summary

PART III – Creating a framework for PEV charging feedback interfaces

9. Proposition of a framework for integrated user interfaces to support beneficial user behaviours regarding PEV charging

PART IV – Developing and testing PEV charging feedback interfaces

10. Creative examples for feedback interfaces beyond energy management – Design Precedents
11. Development process for user interface prototypes in several mediums
12. Presentation of final user interfaces
13. Experiment to evaluate effectiveness of the interfaces
14. Summary of research findings.

2. LITERATURE REVIEW: FEEDBACK AND PERSUASIVE INTERFACES

2.1 Introduction

There is a rich volume of published research that studies the effectiveness of real-time feedback and persuasive interfaces on improving responsible resources management by users. A study by Faruqui, Sergici, and Sharif (2010), for instance, showed that real-time energy feedback could reduce energy consumption by up to 20% in homes with access to energy feedback interfaces.

Researchers are starting to develop interfaces around smart grids[1], which share some similar purposes with the interfaces being discussed in this project. Yet, the literature on smart grid interfaces is still very limited. The most abundant number of precedents with high potential to inform interfaces for PEV charging is available in the literature on home energy feedback and management. Some of these projects are introduced in the following section.

The majority of these interfaces are based on the assumption that providing real-time feedback to users is sufficient for them to engage in more positive behaviour. A successful example of this is the provision of speed feedback to motorists in order to improve their compliance with speed limits (e.g. Chitturi et al. 2006).

Feedback interfaces often work on the understanding that inherent human biases and heuristics can impair reasonable decision-making or foster self-deception. Most importantly, people are often unable to process and apprehend the full extent of the effects of their behaviours, for lack of adequate information. Electricity, being an invisible resource, is a mostly intangible concept for typical users, who lack the empirical understanding of the economic and environmental impacts of their energy consumption patterns.

Because the feedback strategy is anticipated to be the main aspect of the interfaces to be developed by the present project, this topic will be addressed in more detail in this section, followed by an introduction to the field of persuasive technology. This section is intended to be a quick presentation to these topics, rather than an exhaustive review.

Figure 6 illustrates the relevant background literature for the discussion of PEV charging persuasive interfaces. In a larger sphere, the interfaces will be grounded on concepts and significant findings from the realm of pro-social behaviour motivation. A behavioural economics perspective of this topic is explored in TIPSLab report 006-001, with a few of its key aspects highlighted in part 2 of this report.

Persuasive Technology is inserted within this larger realm of motivation of pro-social behaviour and persuasion. As mentioned, a significant number of Persuasive Technology devices adopt feedback strategies, although not all feedback strategies for behavioural change belong to the field of Persuasive Technology.

Resources Management is one of the main foci of current research on Persuasive Technology and it is entirely based on feedback strategies, as far as this project

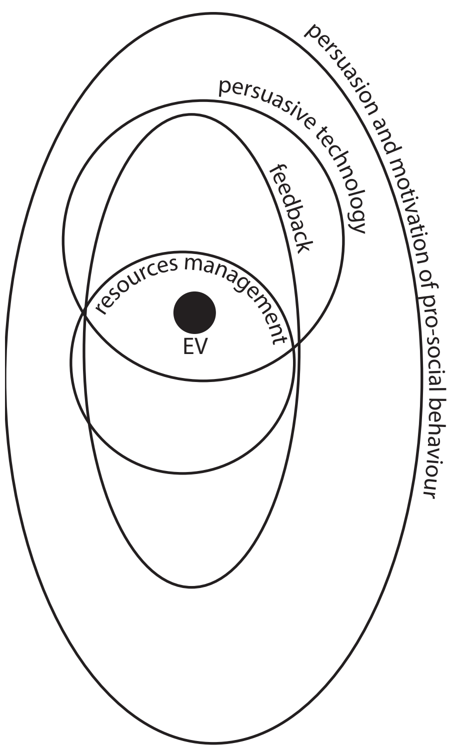


***Figure 6**. The universe of background literature for PEV charging feedback interfaces.*

1. A smart grid is an intelligent network of electricity station and smart meters, which can provide better energy distribution and manage both demand and generation (Beard, 2010)

could cover. PEV charging is, by definition, a problem of Resources Management. Therefore, Resources Management technologies will be explored throughout this report, especially regarding related work and preceding references.

2.2 Feedback for behavioral change

Based on a definition from Control Systems theory by Goyal and Bakshi (2008), Karlin, Ford and Squiers (2014) state that “feedback enables the output of a dynamic system or process (i.e. one whose behaviour varies over time) to be compared to a goal or reference point, in order to enable improved control over that system or process”.

Similarly, the Feedback Intervention Theory (FIT), developed by Kluger and DeNisi (1996), argues that behaviour is regulated by comparisons to preexisting or intervention-provided goals or standards. As Karlin et al. (2004) explain:

> “These standards can be personal goals or comparisons to past behaviour or others in a social group. This is a common concept in previous feedback theories, including goal setting theory (Latham and Locke 1991) and control theory (Carver and Scheier 1981), which both assert that behaviour is generally goal directed and that people use feedback to evaluate their behaviour in relation to their goals. When behaviour differs from the standard, this creates what they call a feedback-standard gap, and it is the desire to decrease this feedback-standard gap that mediates the effectiveness of feedback”.
>
> “Four options are available to individuals when provided with a feedback-standard gap. They can respond by changing behaviour to match the standard, changing the standard to match behaviour, rejecting the feedback or leaving the situation altogether. Both the strength of the goal and the size and direction of the feedback standard gap can impact this choice”.
>
> “Finally, FIT suggests that feedback is effective insofar as it changes the locus of attention of the individual to the feedback-standard gap. Feedback may direct attention to a specific goal or behaviour that was not previously the focus of attention. Thus, it can serve not only to provide information about a behaviour-standard gap but also to draw attention to a specific behaviour in the first place”.

As previously mentioned, the need for feedback information might be imperative because of factors including potential self-deception and lack of means for apprehending the full extent of the outcome of a given behaviour, especially when addressing resource management.

Research has shown that we tend to be over-optimistic and self-deceptive when assessing our own behaviour. For instance, in a study by Tibbals (1996), doctors in a children’s hospital were asked how often they thought they washed their hands in between meeting patients. The doctors estimated a 73% compliance with safety rules, when the actual figure was only 9%.

Meanwhile, electricity is found to be a widely intangible resource. When discussing energy consumption, typical home users find it hard to understand the different power units such as watts and watt hours (Panneerselvam, 2013). Interfaces and visualizations geared towards aligning PEV charging with renewable availability will be required to make the benefits of such alignment intelligible for the common user and suitable to a variety of mental models. These specific issues regarding information delivery formats are further explored in TIPSLab Report 006-002 and will be summarized in part 2 of this report.

Finally, it can be argued that feedback strategies are well accepted by the public. There are numerous successful commercial wearable devices currently being adopted by users to track physical activity, such as FitBit and Nike+ trackers. Based on this phenomenon, it can also be introduced the hypothesis that the limited market success of energy feedback devices is mostly due to people's lack of interest in responsibly managing their energy consumption, in contrast to the interest on physical activity and health. If this assumption is proven correct, the mass implementation of persuasive interfaces for PEV charging will have to concern more about raising interest in the public regarding PEV charging itself than about mitigating rejection for feedback strategies.

2.3 The Basis of Persuasive Technology

Feedback can assume different roles and formats, which are widely explored in the field of Persuasive Technology. This subsection will introduce the main aspects of this field and highlight how feedback can be framed by technology.

Persuasive Technology is a new field proposed by B. J. Fogg, defined by him as a class of technologies that are intentionally designed to change a person's attitude or behaviour. Persuasive technologies fundamentally intend to automate behaviour change (Fogg, 2009), while assuming this change to be voluntary. This means that strategies such as coercion or deception cannot define persuasive technology. Since the seminal work of B. J. Fogg, academia's interest in the field has increased greatly, reflected in the large number of publications in Persuasive Technology to date.

In a book published in 2003, titled *Persuasive Technology: Using Computers to Change What We Think and Do*, B. J. Fogg provides a comprehensive analysis of persuasive possibilities for technology. He identifies that computing technology can play three roles ("functional triad" framework), namely tool, media, and social actor. The ways in which technology can persuade are dependent on the role it plays. The following image (figure 7) summarizes the persuasive possibilities of technologies according to the aforementioned book.

Feedback takes part in several of the strategies presented, but not all of them. For this project, the suitability and application of all strategies will be studied. Despite the fact that feedback strategies are the primary focus of this project, several other strategies (e.g. tunnelling) might be additionally employed in the interfaces' design to enhance effect.

In the following section, applications specifically regarding energy feedback will be further studied, and an appropriate framing for PEV charging feedback will be discussed.

Functional role	Tool: *Increases capability*	Medium: *Provides Experience*	Social actor: *Creates relationship*
Can be persuasive by…	Making target beaviour easier to do; Leading people trhough a process; Performing calculations or measurements that motivate.	Allowing people to explore cause-and effect relationships; Providing people with vicatious experiences that motivate; Helping people rehearse a behaviour	Rewarding people with positive feedback; Modeling a target behaviour or attitude; Providing social support.
Type of pesuasive strategies	Reduction Makes target behaviour easier Tunneling Leads users through a predetermined actions Tailoring Offers tailored information Suggestion Makes a suggestion at the most appropriate time. Self-monitoring – Allows people to adjust their behaviors to achieve a predetermined goal. Surveillance Behaviour is modified by awareness of surveillance. Conditioning Operant conditioning	Cause-and-effect simulation Allows people to observe immediately the link between cause and effect of a simulated behaviour. Environment simulations Rehearsing a behavior in a virtual environment can enable people to change their attitudes or behavior in the real world. Object simulations Simulation in real-world context, i.e. actual objects that simulate a situation.	Physical Realistic appearance and physical attractiveness are related with higher persuasion power. Psychological Personalities that are similar to the users can be more persuasive Language Interactive language use Social dynamics Emulating social dynamics. The concepts of reciprocity and retaliation can be particularly powerful. Social roles Adoption of role, e.g. doctor, teammate, pet.

Figure 7. *Ways that technology can persuade according to B.J. Fogg. Source: adapted from Fogg 2002*

3. SITUATING THE CURRENT PROJECT IN THE ENERGY FEEDBACK LANDSCAPE

3.1 Introduction

As previously mentioned, a large number of mechanisms and devices exist with the intention to achieve behavioural motivation through feedback information. A significant portion of these systems focus on resources management and are commercially available. Academic research is also abundant and has provided us with several performance studies, as well as frameworks and new interface paradigms. The current study is faced with the challenge of situating its research project within the landscape of existing studies and devices around the topic of energy use feedback. It must also build upon such previous efforts and propose new interfaces geared towards PEV charging, taking into account its specificities and requirements.

In order to provide an overview of existing devices and strategies for energy use feedback, especially residential energy use, this project discusses comprehensive classification models found in literature. Next, it proposes a new classification system specific for PEV charging feedback, based on the existing classification models analysed.

3.2 Analysis of classification models in relation to PEV charging

Several authors have attempted to classify feedback devices or establish typologies regarding energy consumption feedback. Darby (2001), EPRI (2009), Ehrhardt-Martinez et al. (2010) and Karlin et al. (2014) are notable examples of such effort. Because these classifications are each collectively exhaustive, i.e. they intend to cover the entire universe of energy feedback types, they serve as good indicators of the energy feedback landscape in which the current project will be inserted. The models proposed by Ehrhardt-Martinez et al. (2010) and Karlin et al. (2014) are both comprehensive, although they take different approaches to the problem. Both will be reviewed in the section[1].

Ehrhardt-Martinez et al. (2010), in a report by the American Council for an Energy Efficient Economy, propose a classification for residential feedback systems and devices which is based on levels. The classification identifies two groups of levels, based on the primary types of feedback users can receive about their energy consumption: 1) indirect feedback provided after consumption, and 2) direct feedback provided in (nearly) real-time. A third group, namely automation, is also considered, but in this case feedback is not necessarily provided to a human operator and action on feedback is presumably pre-programmed.

The authors represent the feedback levels in an onion metaphor (layers); however their model is being presented here in a more straight forward illustration to facilitate understanding (fig. 8). In this model, each level conveys at least the same amount of information as the preceding levels, but with additional improvements.

1. This section does not intend to review specific devices, technologies or companies, but only common characteristics of these systems which allow them to be grouped together for better understanding of the whole universe of existing systems. Specific examples of some of the systems mentioned in the section, as well as of several others not mentioned, are further explored in the following two sections of this document.

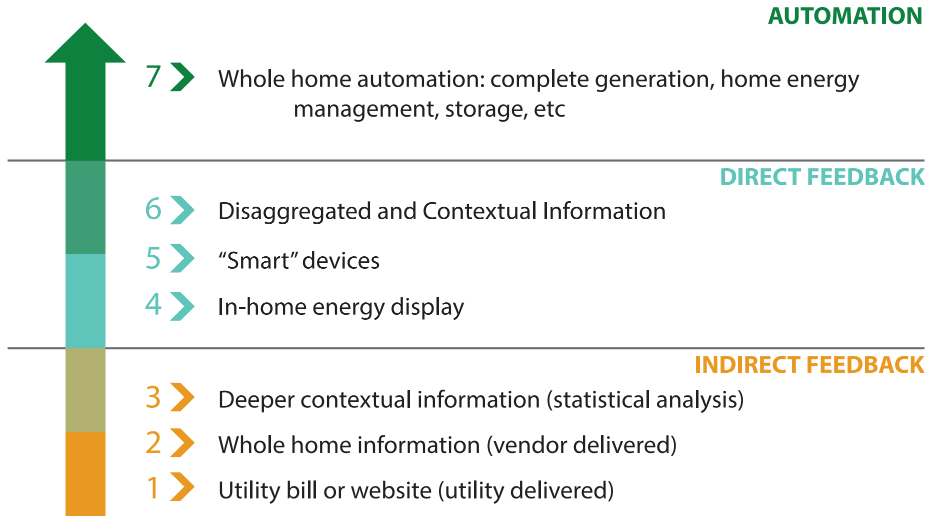


Figure 8. *Layers of energy feedback. Based on Ehrhardt-Martinez et al., 2010.*

The first level, "utility bill or website", encompasses the current monthly utility bill as well as existing and proposed advanced metering installations that provide the consumer with limited Indirect Feedback.

The second and third levels include indirect feedback in whole-house aggregate or appliance/ end use disaggregate feedback types. These types of feedback are typically provided via web and are mostly based on data provided by the electric utility companies, but also from other existing types of data. In the second level of feedback, vendors provide in-depth analysis of consumption (statistical software algorithms might be applied); they also allow for user input and personalized knowledge. The third level additionally includes social contextual feedback to the user. Opower is an example of a company that provides such services, offering Personal Comparisons, Social Comparisons, Setting of Goals, and Action Steps as information to the user. A major advantage of this strategy when compared to the following ones is the fact that it does not require new hardware or infrastructure, so it can easily be implemented on a large scale.

The fourth level, "in-home energy display", provides more tailored and socially-relevant feedback than the previous levels, given its capacity to provide real-time feedback (direct feedback). Data is acquired directly from the power panel, meter or appliance, with typically high accuracy, and is transmitted wirelessly to a display, which can come in a variety of forms and medium[2]. Unlike the previous levels, however, level 4 mechanisms require the acquisition of specific hardware (including sensors) and, oftentimes, specialized installation.

"Smart devices", the fifth level, and "disaggregated and contextual information", the sixth level, consist of smart appliances that can "provide direct, real-time plus feedback, and include appliance-specific information as well as automation" (Ehrhardt-Martinez et al., 2010, p.25). In some cases, they can also receive pricing signals and utility load

2. In home displays (IHD) might have different definitions according to different authors. In this case, the author does not make distinctions between screen-based displays, ambient displays or other formats.

control. These levels comprise a vast set of devices with very different features (e.g. smart outlets, smart thermostat, smart washing machines) and they typically include features such as delayed start. Some of these appliances are able to "receive signals regarding energy supply conditions, such as price and/or carbon emissions, and can use this information to decide when to operate" (p.26). Similarly to the indirect feedback levels, the contextual information defining the sixth level offers the possibility of presenting information in a contextual (personal and social) framing.

Lastly, whole-home automation refers to a networked set of smart appliances with automation enabling-technologies. These systems vary in many respects. Typically, users can decide if they want to be engaged in the information and take responsibility for action, or they may allow system to operate automatically. Notably, in the first case users may gain awareness and develop more sustainable behaviours, while the latter may not provide the same opportunity.

One important thing to notice from the levels' description is the expected variance of cost and effectiveness of the strategies presented across the levels. This key consideration will be further scrutinized throughout this project.

When considering PEV charging, it can be said that all of the categories proposed by Ehrhardt-Martinez et al. (2010) are also applicable as feedback possibilities for PEV charging. However, they might not cover all possible alternatives regarding PEV charging feedback and might fail to appreciate defining characteristics specific to this niche. The categorization system proposed by the current project and presented in sections 4 and 5 of this report learns from the model by Ehrhardt-Martinez et al. (2010) to frame a system specific to PEV charging feedback. The categories are discussed in detail in section 5, with references to the above presented model as appropriate.

Ehrhardt-Martinez et al. (2010) note that significant variation exists within each of the feedback categories they proposed. A major reason is that the categories defined by feedback end up comprising multiple technologies. Another study identified the limitations of this approach and developed a different method for classification.

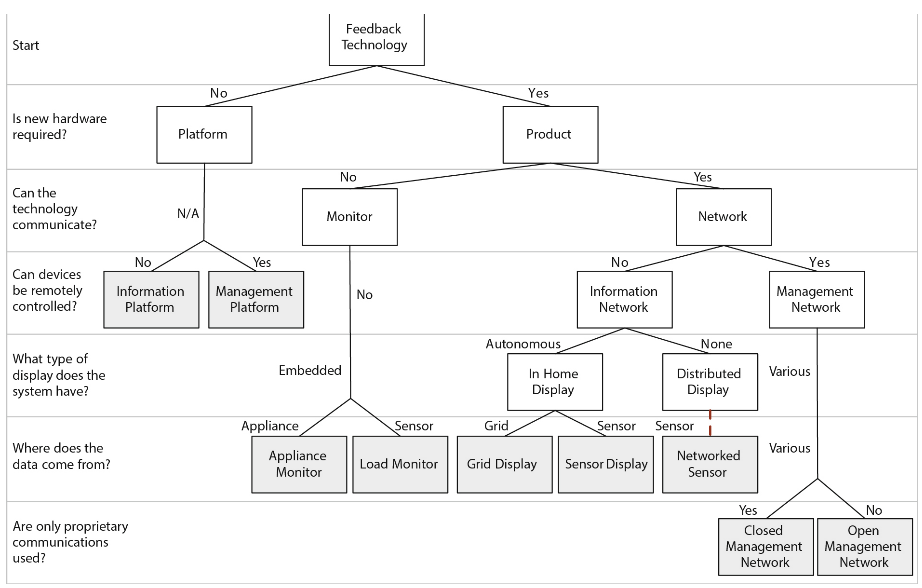


Figure 9. Classification structure of feedback devices by Karlin et al. (2014)

The systematic study by Karlin et al. (2014) proposed a classification structure to account for the diversity in available technologies. They analyzed 196 commercially available devices in the process and published a table containing the classification of all these devices. The diagram in figure 9 illustrates their classification structure.

When considering feedback for PEV charging, especially in terms of aligning charging periods with other events, specific types of data are required as well as specific means of communicating with the user. Based on the classification criteria defined by Karlin et al. (2014), feedback technologies which are most relevant for PEV charging feedback were also identified here. The table below discusses the implications of each group of technological requirements.

Table 2. *Considerations on PEV charging feedback technology based on the classification structure by Karlin et al.*

GROUP OF CHARACTERISTICS	REQUIREMENT FOR PEV CHARGING PERSUASIVE INTERFACES
Hardware *Is new hardware required?*	**Hardware not required, but desirable**. Although platforms can provide essential information regarding renewable availability and peak load periods, feedback on charging behaviour will require the means to acquire data on all charging events. Without this data on charging events, platforms can still be useful as an information medium (not feedback) or they can provide indirect feedback through retrospective analysis of utility data. For direct feedback, several methods exist to acquire data, all of which require hardware: circuit sensors and sub-meters (if EVSE is on dedicated circuit), commercially available outlet sensors, smart EVSEs and intelligent onboard sensors[3] . Of these, only onboard sensors could provide complete charging data. Alternatively, companies with home and public charging stations (e.g. Blink) could combine data from different charging equipment to provide complete charging data. Although direct data streaming from PEVs' onboard computers into platforms would not require extra hardware, this option is not currently available. As for display, both commonly available hardware (no need for purchasing) and new hardware are expected to be effective.
Communication *Can the technology communicate?*	**Communication required.** According to the authors, "communications refers to whether or not the physical component or components of feedback systems are able to communicate with each other and/or pre-existing electronic devices". Ideally, PEV interfaces will require communication with the utility in order to acquire data on power supply and updated time-of-use (TOU) rates. This communication can be via internet or via smart meter. If the interface is not embedded in the PEV, the EVCS or other sensors, it will also need to communicate with these (wired or wireless).
Control *Can devices be remotely controlled?*	**Control not required, but desirable**. No control is required, since it is expected that the provision of feedback alone can trigger user action and consequently enable adequate manual management of PEV charging. However, enabling technologies make it easier for users to adopt the intended charging behaviour, increasing the compliance rate with the feedback suggestions.
Display *What type of display does the system have?*	**All forms of display are acceptable**. Despite the fact that different forms of display might be suitable for different situations, it is desirable that different kinds of situations are covered by the feedback interfaces to be proposed.

3. "More automakers are equipping their PEVs with intelligent onboard sensors, browsers to calculate performance efficiencies (such as distance to next charging station, distance traveled since last charge, cost of the charge in kWhs), and GPS functions that locate the nearest charging station and compare pricing for recharging. Few utilities have meters that can interface with onboard PEV systems but many are exploring this capability for the future." (REVI, 2012)

Data collection *Where does the data come from?*	**Data from Grid AND (Appliance OR Sensor).** Karlin et al. (2014) define three sources of data: the meter or the utility (grid), the feedback product itself (sensor), and existing home appliances or devices (appliance). For PEV charging feedback, devices will preferably be a hybrid of these. They need to receive data from the grid but also from the PEV charging system directly (appliance) or indirectly (sensor). The classification structure proposed by Karlin et al. (2014) therefore does not support the ideal PEV charging feedback this project is proposing, given the classes are supposed to be mutually exclusive. However, if a feedback device is only based on one of these data collection categories, it could still provide PEV charging feedback.
Protocol *Are only proprietary Communications used?*	**Different communication protocols can be used**. Whether the device uses public or non-standard communications protocols, it would not interfere with the device's capability of providing feedback. However, by adopting public communication protocols, a step further could be taken regarding charging control: the possibility of Utility Controlled Charging (UCC).

This identification of technological requirements for PEV charging feedback is expected to assist in the definition of which types of interfaces the current project should focus on for reference and further development. However it should be noted that none of the classification models surveyed during this research (including the two presented in this section) can be considered fully applicable for understanding the full range of feedback possibilities in the context of PEV charging.

Additionally, PEV charging presents a unique challenge for resource management, as previously discussed in this document, which requires the appreciation of different circumstances than those considered when addressing home energy feedback systems. The next section will propose a new classification model specific for PEV charging feedback, departing from the models presented so far. Finally, in the subsequent section, precedent projects will be analysed and classified according to the new model.

4. PROPOSAL OF NEW CATEGORIZATION MODEL FOR PEV CHARGING FEEDBACK

The first thing to consider when addressing PEV charging is the fact that PEVs are not static appliances and that a same vehicle might be charged in a variety of places and circumstances routinely. In the construction of our classification model, we identified five typical spatial spheres in which PEV charging feedback potentially operates: personal, home, work, in-car and public charging stations. Such spaces do not necessarily refer to where PEV charging takes place, but rather in what context feedback information is provided.

Home, work and public charging stations are the three major locations where PEV charging commonly occur. Feedbacks classified in these spaces are provided solely within the environment that each space comprises. They might provide feedback for all users of the location aggregately or for current user specifically.

Personal and in-car spaces are not fixed to a single location, but rather accompany the user and the PEV, respectively. Personal interfaces can be accessed by the user at any moment and in any location, while in-car interfaces can be accessed at any moment inside the vehicle, by any user operating it.

Apart from the spatial component of PEV charging, the current range of possible feedback types is the other key aspect to be considered when analysing potential

PEV feedback interfaces. Based on the categories proposed by Darby (2001), EPRI (2009) and Ehrhardt-Martinez et al. (2010), as well as on an extensive survey on PEV appropriate interfaces, we define five general types in which format PEV charging feedback might occur: indirect feedback, direct feedback, direct control, autonomous systems and third party control.

Indirect feedback refers to mechanisms which provide feedback after the fact, commonly in cumulative format. In contrast, direct feedback is feedback provided in nearly real-time; it can be cumulative at varying extents or present instant-only information. Direct control refers to mechanisms which provide direct feedback but also allows degrees of control over the charge events through their interfaces. Direct control might include features for remote control, programmed charge, etc.

Autonomous systems refer to the complete automation of the charge events. In this case, feedback is provided as a performance report, allowing the user to make adjustments if necessary. The last type, third party control, includes systems for monitoring Utility Controlled Charging (UCC).

It is important to notice that each feedback type might operate differently regarding users' charging decision. For instance, real-time interaction is expected to exert a different quality of influence and engagement than more passive setups (e.g. user selecting charging preferences in automated system).

The crossing of the five feedback spaces with the five feedback types results in a matrix defining 25 possible PEV charging feedback categories. The name of each category is composed by a combination of the feedback space title with the feedback type title, e.g. Personal Indirect Feedback. Figure 11 illustrates the matrix, specifying the final categories by name. The categories' slots with a hatch fill, 8 in total, indicate categories that are being presently disregarded due to lack of applicability in current PEV charging scenario. 17 categories remain and will be explored in the following section of this report.

Figure 12 provides application examples for each category, when available. The indications of minimum required technology are based on the taxonomy by Karlin et. al (2014).

TYPE / SPACE	Indirect Feedback	Direct Feedback	Direct Control	Autonomous Systems	Third Party Control
Personal	Personal Indirect Feedback	Personal Direct Feedback	Personal Direct Control		
Home	Home Indirect Feedback	Home Direct Feedback	Home Direct Control	Home Autonomous Systems	Home Third Party Control
Work	Work Indirect Feedback	Work Direct Feedback	Work Direct Control	Work Autonomous Systems	
In-car		In-car Direct Feedback	In-car Direct Control	In-car Autonomous Systems	
Public charging	Public Charging Indirect Feedback	Public Charging Direct Feedback			

Figure 11. *Classification matrix for PEV charging feedback interfaces*

TYPE / SPACE	**Indirect Feedback**	**Direct Feedback** (real-time)	**Direct Control** (coupled with feedback)	**Autonomous Systems**	**Third Party Control**
Personal	i B Utility/vendors billing, websites & (e)mail reports	A L i Mobile, web applications, displays with user recognition	M Mobile & web applications with control capabilities		
Home	B Information sign for cumulative home charging stats	A L In-home display, ambient display, station-attached display	S Built-in display in Smart charging station, Home management devices	((O ((C	((O
Work	B Information sign for cumulative work charging stats	A L stand-alone display, ambient display, station-attached display	S Built-in display in Smart charging station	((O ((C	
In-car		A In-car display	S In-car charge programming	((O ((C	
Public charging	B Information sign for cumulative charging stats at station	A L Station-attached display, indicative envelope & signage			

Figure 12. Classification Matrix for PEV Charging Feedback with application examples.

MINIMUM REQUIRED TECHNOLOGY

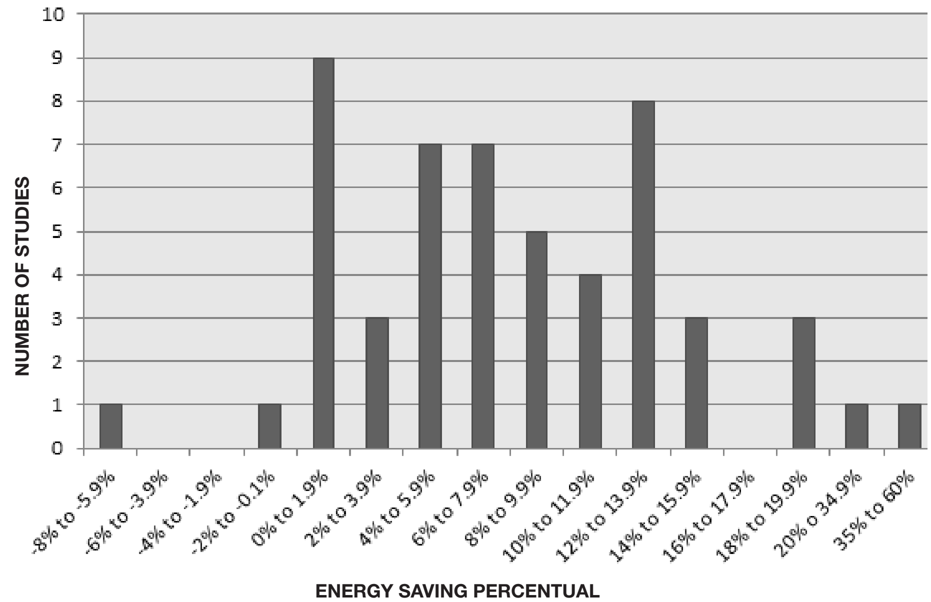
- B - Billing & paper reports
- i - Information platform
- M - Management platform
- B - Appliance monitor
- L - Load monitor
- G - Grid display
- S - Sensor display
- N - Networked sensor
- ((O - Open Management Network
- ((C - Closed Management Network

Similarly to the categories proposed by Ehrhardt-Martinez et al. (2010) for residential energy use feedback, the categories here proposed for PEV charging feedback might vary greatly in terms of cost and effectiveness. Graph 1 presents the frequency distribution of the performance of several feedback devices, assessed by different studies and summarized by Ehrhardt-Martinez et al. (2010) in a comprehensive table. The graph illustrates how widely the performance of devices can vary towards their objective of reducing home energy consumption.

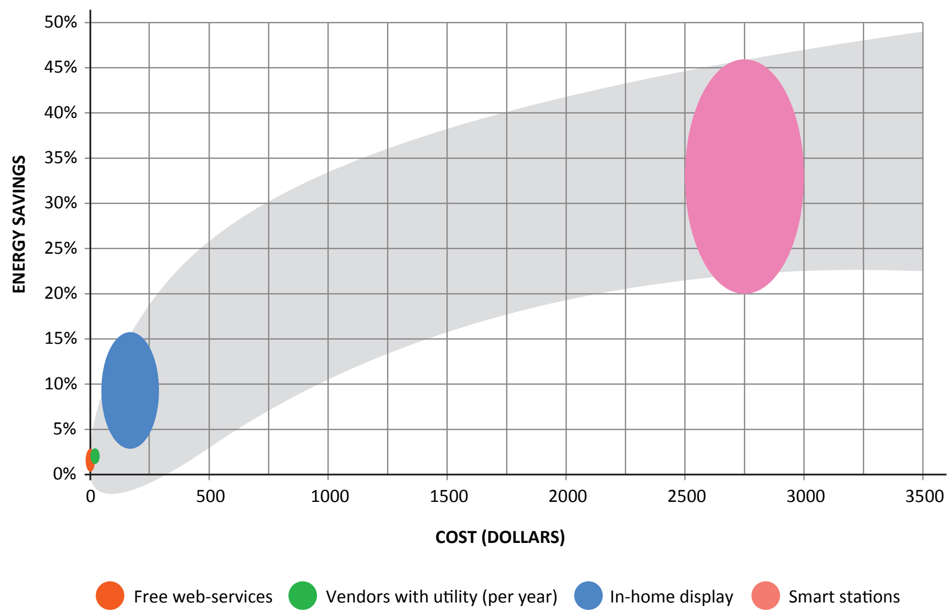
Aspects that might exert major influence on effectiveness are: (a) whether feedback is direct or indirect, and (b) whether feedback is coupled with enabling technologies to support users in taking action. In the matrix proposed in this project, effectiveness is expected to increase from the left column of the matrix (indirect feedback) to the right columns (until Autonomous Systems)[4]. However, when considering mass adoption, deployment costs also increase in the same direction.

Therefore, studies of Cost versus Effectiveness to identify the most efficient alternatives in the context of British Columbia could be very valuable. Graph 2 provides an estimation of such Cost versus Effectiveness relation with regard to home energy feedback. The costs were estimated from market survey, while effectiveness is based

4. Third Party Control is disregarded for composing a completely different type of PEV charging system.



***Graph 1.** Frequency distribution of studies' results that measure performance of feedback devices. Data source: Ehrhardt-Martinez et al., 2010.*



***Graph 2.** Analysis of cost versus benefits of home energy feedback/management devices.*

on results from research[5] investigating specific feedback methods and devices.

Additionally, surveys to identify rates of spontaneous adoption of smart home systems and other technologies among PEV buyers could point towards good opportunities for persuasive interface development, as well as for reducing the cost of implementing certain alternatives. A survey by Axsen et al. (2013) suggests that a significant portion of early mainstream buyers of PEVs in British Columbia have technology-oriented

5. Research results compiled by Ehrhardt-Martinez et al. (2010). Vendors' results, exceptionally, are based on Ayres et al. (2012).

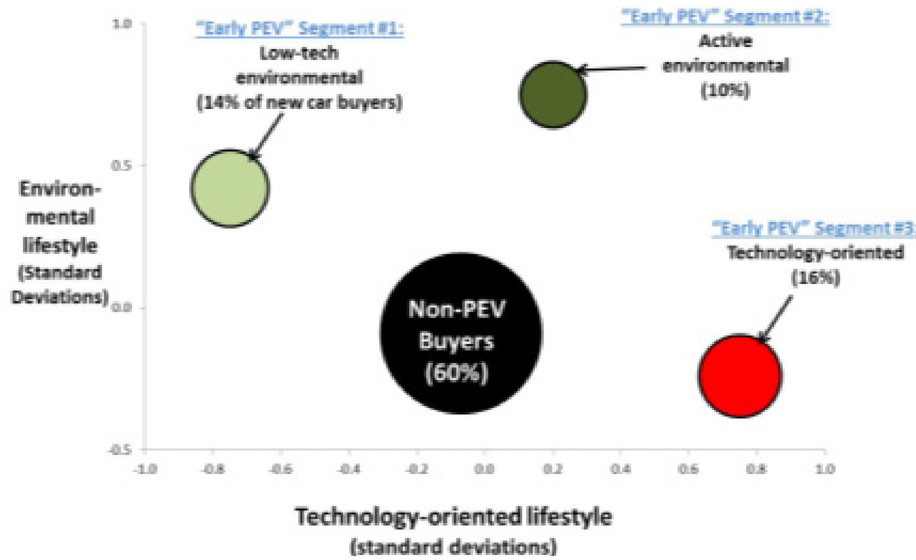


Figure 13. Comparing "early mainstream" PEV buyer segments in BC by lifestyle. Source: Axsen et al., 2013.

lifestyles (fig. 10), potentially intersecting with the group of smart-appliance adopters. For this reason, further studies on BC users' profile, opinions and opportunities are presented in section 5 (part 2) of this project.

Apart from the two defining aspects structuring of our classification model, i.e. space and type, a critical aspect to identify the ideal interfaces to be developed and implemented is context. As Karlin et al. (2014) points out, further research is still needed in order to identify how feedback is best applicable in different contexts. The extensive survey carried out by Ehrhardt-Martinez et al. (2010), analyzing a wide range of energy feedback research results, points toward the complexity of factors that might play a role in interface success.

Part 2 of this project will focus on defining the context on which the interfaces to be developed will act. Part 1 provided a background research to clarify the exploration space for potential PEV charging feedback systems. To finalize the background research, section 5 analyses and classifies several existing feedback interfaces, devices and mechanisms according to the categorization model proposed in this project. Each category will be also discussed in further detail.

5. CLASSIFYING EXISTING AND ANTICIPATED INTERFACES FOR PEV CHARGING FEEDBACK

The classification matrix proposed by this project is a new model highly focused on feedback interfaces for PEV charging. As previously discussed, it is based on existing classification models for energy feedback, as well as on an extensive survey on feedback interfaces. In this section, we will present some of the systems and interfaces surveyed which were judged most relevant for the discussion of PEV charging feedback. They are organized in categories according to the classification matrix. When no interface exists to represent a category, or when a category is under represented, generic propositions are also offered for clarification.

For reference, a schematic version of the classification matrix will be presented with each category to facilitate identification.

All systems and interfaces mentioned or proposed in each category use strategies of tailoring and self-monitoring, as described by B. J. Fogg (2002). Whenever more strategies take place, they will be mentioned and/or explained accordingly.

	Indirect F.	Direct F.	Direct C.	A.S.	T.P.C.
Personal					
Home					
Work					
In-car					
Public					

5.1 Personal Indirect Feedback

Personal Indirect Feedback refers to aggregate information delivered directly to one individual about his/her PEV charging activity, in a regular basis.

In the scenario of home energy feedback, several companies exist whose intention is to improve energy efficiency in households by changing people's behaviour. With such intent, they deliver a report to the user via conventional mail, email or website portal. At a minimum, the report contains information about how the user has been consuming energy. Additionally, their strategies for improving behaviour typically include normative-based information (e.g. presenting comparative data to neighboring households) and other mechanisms developed with foundations in behavioural sciences.

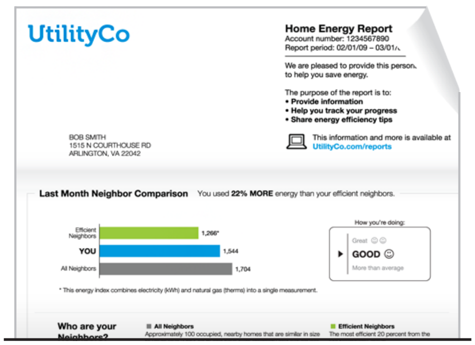


Figure 14. *Opower's feedback letter. Source: Opower's official website.*

Data is provided by the utility or the meter and enhanced with extra data sources and customized guidance. Even if direct data from PEV charging is not available, these companies could still provide helpful analytics by making best use of available resources and information. It would also be possible for such companies to provide efficiency tips specific to PEV charging and, in some cases, real-time information to help PEV users save money. Some companies, for instance, send customers timely emails with information to support time-specific behaviours. However, despite the potential usefulness of these approaches, this survey did not find companies addressing PEV charging as above described, although some demonstrate interest in PEV data and integration (e.g. Opower[6]).

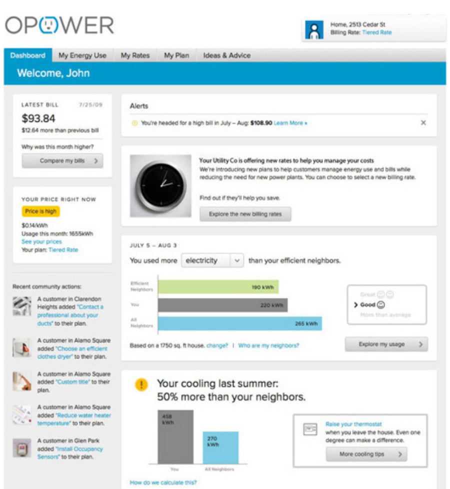


Figure 15. *Opower's Dashboard.*

The table below, retrieved from Ehrhardt-Martinez et al. (2010), compares three companies that provide indirect residential feedback to the users, using data received from the utilities or from the meter.

Table 3. *Summary of energy feedback companies. Source: Ehrhardt-Martinez et al., 2010.*

Company	Feedback Technology	Feedback type	Behaviour Principles
Opower	Depending on utility, send monthly or quarterly mailings, and/or provide Web site with newly forming social networks.	Indirect including: Household information and advice, web-based energy audits, billing analysis, estimated appliance-specific, CO2, kWh, and costs.	Social Comparisons, Goals, Personal Comparisons, and Action Steps.
Efficiency 2.0	Social community website with energy and water consumption feedback.	Indirect including: Household information and advice, web-based energy audits, billing analysis, estimated appliance-specific, CO2, kWh, $, and other units.	Social Comparisons, Goals, Competitions, Social Networks, Personal Comparisons, and Action Steps.

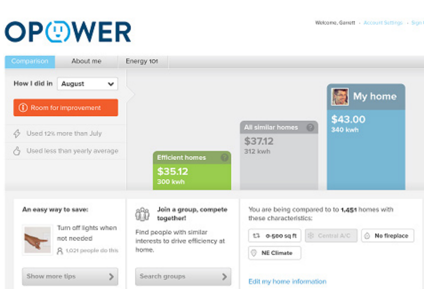


Figure 16. *Opower's Facebook app.*

6. Opower rebranding: http://www.greentechmedia.com/articles/read/opowers-evolution-will-the-efficiency-firm-soon-be-a-solar-integrator

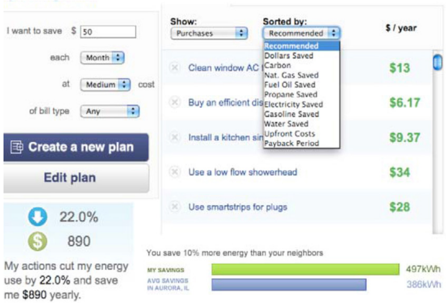


Figure 17. Efficiency 2.0 Dashboard.

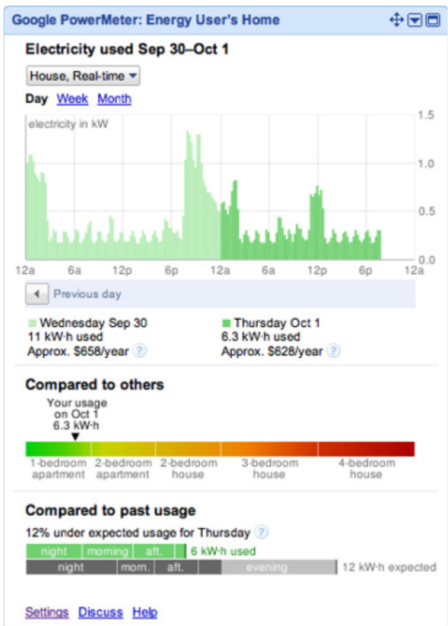


Figure 18. Google's Power Meter Dashboard.

	Indirect F.	Direct F.	Direct C.	A.S.	T.P.C.
Personal					
Home	●				
Work	●				
In-car					
Public	●				

Figure 19. Billboard with feedback on water availability in Penang, Malaysia.

Google.org	PowerMeter on Website, including Google social Networks.	Indirect including: Household information, estimated household and monthly bill, estimated appliance-specific.	Social Comparisons, Goals, and Personal Comparisons.

Opower stands out among such companies, for achieving successful position in the market[7]. This company offers their services directly to utilities, which dismisses the need for convincing end users individually in accepting feedback services. The opt-out nature of this strategy ensures that a large number of people will receive this service, in contrast to the low numbers typically found among opt-in contracts.

Opower uses utility data combined with other data sources, which are presented to the users in efficient feedback formats for behavior modification. Research publications rate their success in reducing energy consumption by around 2% in the households that receive their services (Ayres et al., 2012).

The main vehicle for feedback provision used by Opower is a paper letter submitted by conventional mail (fig. 14). An image of their web-based dashboard is also presented in this page (fig. 15), followed by the company's facebook app (fig. 16).

Efficiency 2.0 and Google.org's PowerMeter have not been as successful in the market. Efficiency 2.0 uses similar data strategies as OPOWER and offer customized Savings Plan based on user parameters and inputs (fig. 17). PowerMeter (fig.18), by google's NGO branch, intended to make information accessible in order to leverage sustainable behaviour. However the project was discontinued in 2011 due to low adoption.

The same kind of strategy observed in these home energy services can be adopted with particular interest to PEV charging. Data can be provided by onboard computers, for comprehensive feedback. Alternatively, it can be provided by a sub-meter or separate meter, power outlet monitor, whole-home monitor analyst, among other home charge recording instruments.

One key characteristic of Personal Indirect Feedback systems is that it is addressed to one user specifically instead of a group of users from a location.

5.2 Home, Work and Public Charging Indirect Feedback

In these categories, feedback is addressed to the group of users of a specific location's charging facilities. The billboard in figure 19 demonstrates an initiative which intended to provide feedback on water availability to an entire state's population, in Penang, Malaysia.

Examples on energy consumption feedback for specific locations are not as available as they are regarding person-addressed feedback. Also, no example readily applicable for PEV charging was found in the survey conducted by this project. Nonetheless, we illustrate below one possible alternative for PEV charging indirect feedback in a place-based setting, namely via a public-addressed report poster (fig. 20).

A report poster is a quite conventional format for communicating performance, since it can contain a significant amount of information. Additionally, less conventional formats

7. https://www.greentechmedia.com/articles/read/OPower-Making-Millions-in-Home-Energy-Efficiency

could be used to provide immediate and eye-catching information (“hints”), although in less detail. The mock-up below suggests this alternative (fig. 21).

In current metering settings, feedback for place-specific PEV charging is not readily available due to data aggregation. Again, sub-meters or dedicated meters, although currently uncommon, can be an alternative to provide EVSE-specific feedback at frequent intervals. Power outlet monitors and meter analyst software are also options. Once data is collected, useful information can then be presented to the group of that EVSE’s users through one of the methods illustrated above. Note that in both examples the display of information can be manual, i.e. put in place by a human agent.

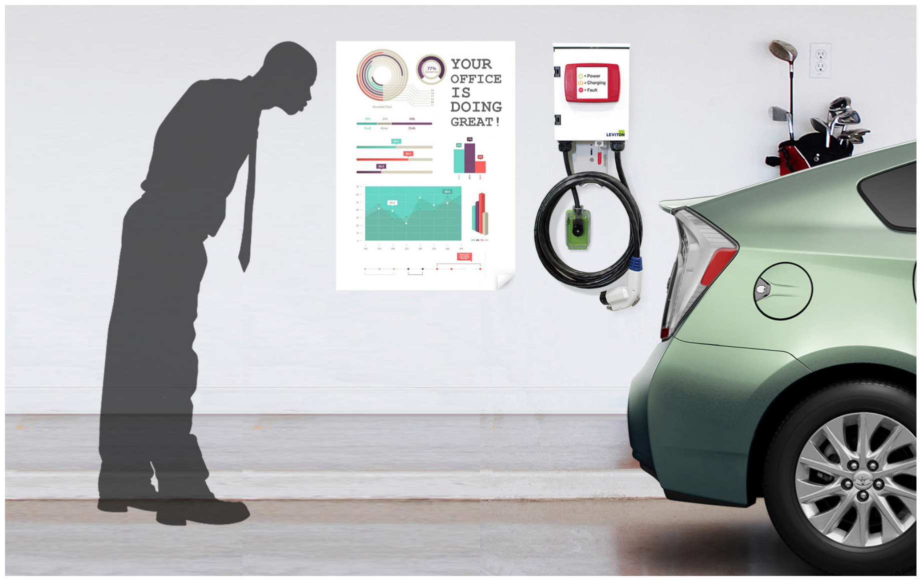


Figure 20. *Proposition of PEV charging indirect feedback in a place-based setting. Source: authors.*

Figure 21. *Adding information to a conventional level 2 station. (Left) Unaltered station, (middle) positive feedback. (right) negative feedback. Source: authors.*

	Indirect F.	Direct F.	Direct C.	A.S.	T.P.C.
Personal					
Home					
Work					
In-car					
Public					

5.3 Personal Direct Feedback

The category “Personal Direct Feedback” approaches direct feedback delivered to an individual specifically, regardless of where data is collected and delivered. This category presents a potentially large range of applications, because it is anticipated

Figure 22. GE Nucleus devices

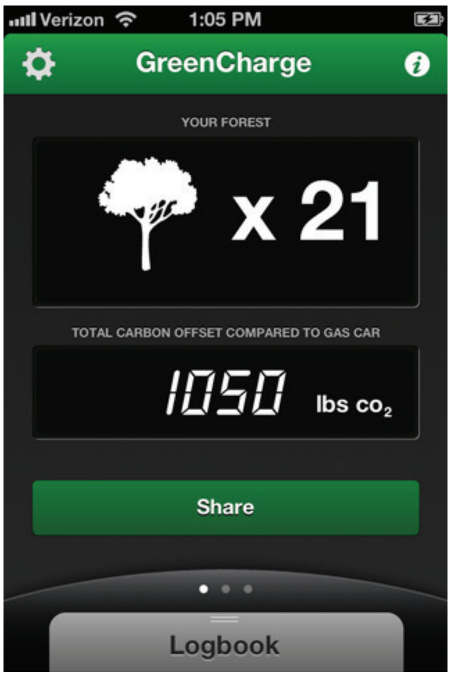


Figure 23. GreenCharge app screen shots - Source: http://www.greenchargeapp.com/

Figure 24. Chargepoint website dashboard

to function through mobile devices (smartphones, smart-watches, smart-glasses) and web platforms, which are very flexible and powerful vehicles.

Currently, direct feedback devices are widely available in many formats, a few of which are specifically directed to PEV users. Some general energy feedback devices might also be suitable for PEV charging feedback. A major advantage of this approach is the possibility of providing real-time data from the utility (e.g. TOU pricing) coupled with real-time usage data. Additionally, because personal systems typically make use of smartphones and other available personal devices that users already own, they can be less costly than other alternatives.

GE's Nucleus (figure 22) is an example of home energy monitor device that deliver direct feedback to users via a personal mobile app or personal web app. This sort of system could inexpensively integrate information regarding home PEV charging, by using an easy-to-install sensor in the EVSE's power outlet or dedicated circuit.

A few apps also exist which are designed specifically for PEV charging and driving information. The app presented below (figure 23), namely GreenCharge, keeps a log of a PEV's charge status and comparative environmental information in regard to gas powered vehicles, among others. This app, however, is not designed to assist the users in charging during specific periods. Although a few apps classified as "Personal Direct Control" start to address charging periods, no app or device classified as "Personal Direct Feedback" during this survey was found to address such concern.

A few web-based services also exist to manage public PEV charging and PEV fleets, despite the access to data often being more limited. One representative example is ChargePoint (figure 24). This web-based service assists the driver in finding convenient public charging stations in proximity, while providing charging status information and other cumulative feedback information on charging outcomes, such as greenhouse gases saved.

Similarly to GreenCharge, this interface starts to address feedback on environmental impact graphically. Additionally, it employs personal and social comparisons. The feedback is a secondary feature, coupled with other useful primary features, such as finding stations and providing information on their current availability. The grouping of different useful features is expected to increase exposure to the feedback mechanisms. The purpose of Chargepoint's interface, however, isn't to induce a green charging behavior and their dashboard hasn't been developed with the intention of nudging positive behaviour.

The realm of applications for PEV charging feedback is still under explored, especially when considering the potentialities of modern mobile devices. Apart from delivering real-time reports, they can also associate information with GPS locations; therefore assuring information would be delivered at the most ideal moments (see "suggestion" concept, by B. J. Fogg). Augmented reality is also an interesting resource enabled by mobile devices with camera. Using augmented reality, information on green charge status can be registered to the real world in real time, making it both efficient and entertaining. Figure 25 illustrates one possible application using augmented reality, proposed by this project.

However, mobile devices are not the only ones that can support features different than conventional real-time reports. Web applications can also make use of different

Figure 25a. *Green charge status in augmented reality. Example portrays character registration on DC charging station. Source: authors.*

Figure 25b. *Unedited photograph of DC station used for registering augmented reality character.*

	Indirect F.	Direct F.	Direct C.	A.S.	T.P.C.
Personal					
Home					
Work					
In-car					
Public					

Figure 26. *Wall-mounted display. EDGEhome solution, by Green Edge Technologies*

persuasive strategies, such as cause-and-effect simulation.

Researchers like Sheppard (2012) are looking into visualizing climate change as a tool for changing people's behaviour. A visual scenario simulation associated with PEV charging feedback could be one among possible strategies (e.g. "how would the planet look like if everyone uses electricity like you do?").

Lastly, one relevant strategy that has been overlook by the applications surveyed in this study is gamification. As suggested in figure 24, gamification can be easily adopted in mobile and web applications, potentially increasing its effectiveness.

5.4 Home and Work Direct Feedback

Monitoring systems also exist with integrated display to provide direct feedback in a specific spatially-localized apparatus. An advantage of these systems is that they can make themselves visible without the need for the user to actively access them. In some cases, it is also possible for these systems to present themselves to the user at the exact time and place the user engages in the activity we want to nudge, i.e. when initiating charge. On the other hand, these systems also require dedicated displays, which make them more expensive than the previous category.

The EDGEhome solution, for instance, comprises a wall-mounted display as main feedback vehicle (fig. 26). The dashboard makes monetary savings its main persuasive feature, with end-specific detailing.

The Aware Living interface system (ALIS) is another example of in-home system that supports residents in awareness of resource use with mechanisms to motivate green behaviour. ALIS was part of the West House project, in Vancouver, a collaboration between Simon Fraser University, the City of Vancouver and BC Hydro Power Smart, among others. The figures 23 and 24 show two dashboard screens from ALIS's in-home display.

ALIS does not present comparisons with other households as its main persuasive feature, although it does support social comparisons. Again, the systems main feature focuses on highlighting financial benefits (rewards) for improving behaviour. Additionally, the system uses other strategies to achieve behavioral change such

Figure 27. *ALIS main dashboard*

Figure 29. Wattson

as gamification ("challenge" panel), suggestions for improvement, neighbourhood information, and end-specific feedback.

Apart from the wall-mounted display, ALIS also employs an ambient display. The projected lights of the display (fig.27) indicate the water consumption of the day. Other ambient displays also exist to provide feedback on energy consumption, such as the Wattson system (fig. 28). Wattson, like other similar devices, is a commercially available product.

None of the systems or services discussed in this category offer specific feedback tailored towards green PEV charging. However such systems could be easily adapted to include PEV charging feedback.

Ambient displays can be particularly useful in office spaces, for allowing information to be seamless and yet easily available to all. With stand-alone displays and station-attached displays some of the strategies discussed in the previous category are also applicable, like cause-and-effect simulation. Lastly, we suggest that smart envelopes can also be an alternative. In such case, systems like those illustrated in figure 20 could provide real-time information without the need for a human operator. However, because smart envelopes can be costly, they will be further discussed as a viable alternative for public stations only.

Figure 28. ALIS ambient display (right) and ALIS ambient display patterns (left).

	Indirect F.	Direct F.	Direct C.	A.S.	T.P.C.
Personal					
Home					
Work					
In-car		●			
Public					

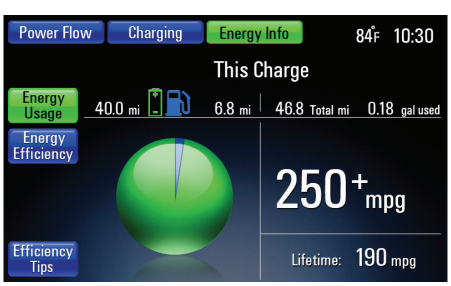


Figure 30. Chevy Volt dashboard

5.5 In-car Direct Feedback

For PEV charging feedback systems to relate directly to charging activity, they would have to be supported by PEVs' and EVSEs' interfaces. Both vehicles and charging equipment often provide feedback for several aspects of charging, but feedback for better charging behaviour is still unaddressed, as far as this study could identify. The image in figure 30 illustrate the dashboard in a Chevy Volt displaying charge information.

EcoScore (fig. 31) is another in-car system available in several vehicle models. It was designed to provide feedback to drivers regarding their driving behaviour and, like previously discussed systems, also adopt a gamification strategy for behavioural change. It does not address charging behaviour, but focuses on the driving efficiency to save fuel and reduce emissions. Some HEVs and PEVs have similar functionalities in their dashboards.

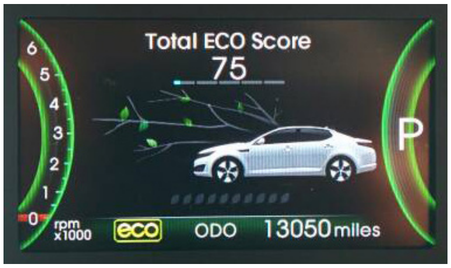


Figure 31. *EcoScore*

	Indirect F.	Direct F.	Direct C.	A.S.	T.P.C.
Personal					
Home					
Work					
In-car					
Public					

Figure 32. *WattStation, by General Electric*

Figure 33. *Blink stations (bottom) and their interface (top)*

Very recently, Apple, Google and Microsoft have unveiled dashboard navigation and entertainment systems for cars which could provide a great opportunity for PEV charging feedback applications. The systems are called CarPlay, Android Auto and Microsoft in the Car, respectively. They will be able to run applications developed by independent developers in a hands-free fashion, making previously outdated car dashboards fully capable of adopting new in-car interfaces for PEV charging management, as easily as installing a smartphone app.

In-car interfaces cannot be graphic-heavy, but rather operate as seamlessly as possible. The study of audio interfaces is recommended. In this case, considerations on the persuasive functional role of social actors, as described by B.J. Fogg[1], might be appropriate.

5.6 Public Charging Direct Feedback

Apart from PEVs' dashboards, the charging stations themselves – or EVSEs – are opportunities for feedback information to be conveyed at the exact time and place charging activity initiates. Again, they normally provide feedback on charge status, but don't address charging behaviour. The WattStation (fig. 32), produced by General Electric and designed by Yves Behar, uses colors and a screen to display charging status. It is an example of high-end EVSE with sophisticated communication resources. Most public stations, however, offer fewer opportunities.

Manufacturers such as Blink, which provide home charging stations as well as public Level 2 and Fast Charging stations (fig. 33), have the advantage of covering the whole range of charge events from users, and are therefore able to provide comprehensive feedback on charging behaviour. Figure 33 presents a screen image from Blink's interface, which offers cumulative feedback information in numeric format about several aspects of charging, including off peak consumption.

Typically, charging stations can recognize a user through card verification or other keys, which can allow administrators to provide cumulative information on charging through websites or other mediums when a built-in display in not available. Administrators can also award points to the user according to use time or provide other sources of incentives. However this is not an embedded feature (only user verification is) and commonly stations do not have interfaces designed to inform the user about green charging or incentives in real time.

When models of public charging stations that don't support green charge feedback are already installed, this feature could be incorporated by installing add-on sensors and displays to the station. Also, smart envelopes, or wraps, can be used to provide the necessary feedback.

Currently, the public charging stations being deployed in BC are covered with wraps serving strictly branding and signage purposes (fig. 4). The envelopes and the station design themselves carry the potential to also serve informative purposes regarding "green" energy, by providing hints to the users. As also illustrated in figure 4, public charging stations are typically accompanied by horizontal (pavement marks) and vertical (sign posts) signalization, which could also serve instructional purposes in real

1. Refer to Figure 7 of this report, "Ways that technology can persuade according to B.J. Fogg".

Figure 34. Enveloped DC Fast charging station in Surrey

Figure 35. Expiry Date / The Things Far Away Beyond Numbers, by Ko Yang.

Figure 36. Powercheck by Duracell

Figure 36. Platform dynamic boarding information system by ProRail in Holland

time.

Although envelope and signalization may not be able to convey the same amount of information as displays, they can communicate to drivers at a distance, allowing them to know the status of electricity without the need to stop the car and approach the station.

Our survey didn't find envelope or signalization for EVSE designed to provide information in real time. Few examples, however, are available of envelopes and packaging designed to provide real-time feedback for consumers, which suggest the application might also be possible for PEV charging.

"Expiry Date / The Things Far Away Beyond Numbers" (fig. 35) is a project developed by the designer Ko Yang. It is a milk carton that changes its color to indicate the freshness of its content. Another design by Naoki Hirota follows the same purpose. "Fresh Label" turns its color from white to blue, once a perishable product is past it's due, making the item unscannable. The label has two layers: one of info for the food with the barcode, and another on top with special ink reactive to ammonia.

However such examples, as presented below, are solely design projects without further development and implementation as commercial products. Their functionality cannot be verified, but they still serve as design references in this category.

Examples found of electricity indicators embedded in packages or envelopes are not as inventive regarding their design. Figure 36 illustrates the Powercheck technology by Duracell, which indicates how much power remains in the battery once the white circles on each side of the battery are pressed.

Similarly, feedback displays to indicate charge levels mostly consist of a power bar that decreases in length as charge become less available.

Regarding signalization, examples were also lacking regarding PEV charging specifically. It was about organization of public transit where they were most abundant. Examples exist from simple bus-stop real-time information systems to a sophisticated "platform dynamic boarding information system" by ProRail in Holland (fig. 37), which indicates how full is each wagon, along with other information such as available support for bicycles.

Again, we believe that such ideas can be part of the scope of interfaces considered for public charging stations, communicating relevant information regarding green charge.

	Indirect F.	Direct F.	Direct C.	A.S.	T.P.C.
Personal					
Home					
Work					
In-car					
Public					

5.7 Personal Direct Control

PEVs are being increasingly integrated in the scope of smart homes. For the past few years, energy management and PEV manufacturing companies have engaged in developing Home Energy Management Systems (HEMS) to also manage PEV charging. These systems feature important enabling technologies, such as programmed charging and charging criteria.

Tendril, a company that offers energy management services, is one of the first in the sector to address PEV charging. It employs a physics-based model to calculate whole-home disaggregated consumption information and it provides feedback to users through reports, web portals and mobile applications, according to its website. They employ behavioral methodologies to improve the effectiveness of information, namely contextual references (comparison within the community) and gamification (providing points for users who achieve goals).

Since 2012, Tendril has included PEV charging in its management system. Tendril Connect(TM) is the technology that provides the connectivity to integrate the PEV smart charging station into the home, the local utilities and to PEVs. Tendril Energize(TM) is a suite of applications including a home energy management web portal, through which the user can manage the EVSE. The following image (fig. 37) illustrates the web portal access to charging information.7 The “current status” panel provides information on how far the vehicle can drive with the current charge level, how long before the PEV is fully charged and costs associated with the charging.

The tendril system is, most importantly, a significant enabling technology. For instance, the web and mobile application allow users to start or stop charging remotely. They also

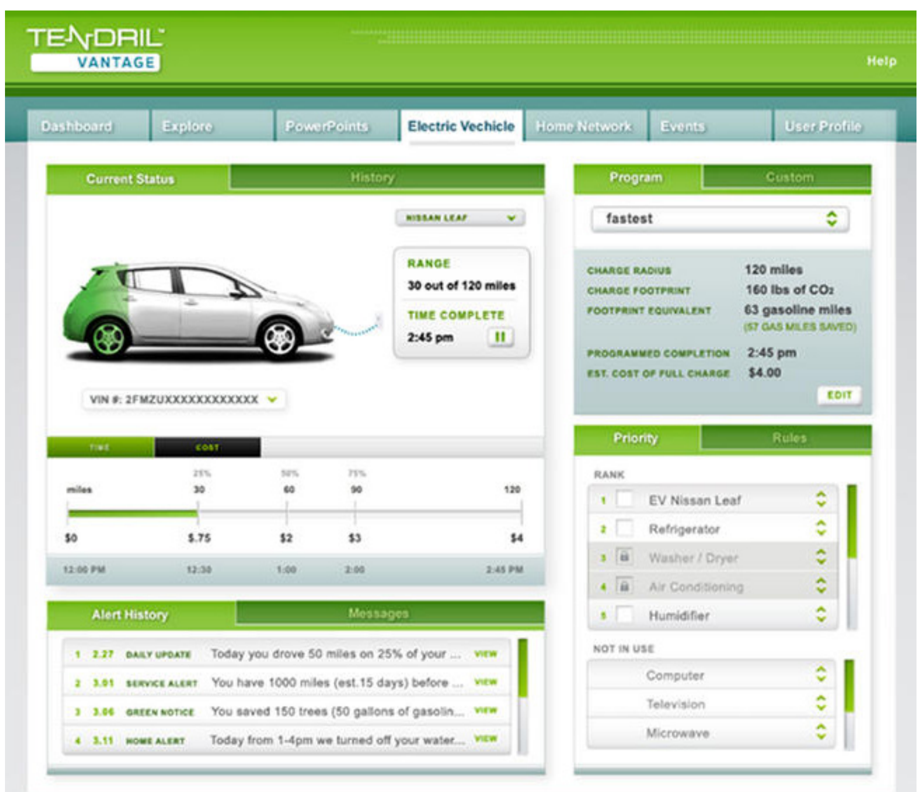


Figure 37. *Tendril web portal for PEV management*

offer the option of "set and forget", in which users can select a pre-defined program for automated charging, such as "fastest charge", "cheapest charge" or "greenest charge". They can also set a rule, such as how many miles of charge must be available at a given time and date. These settings are available in the "program" panel, which provides estimates regarding carbon footprint, equivalent gasoline consumption and cost, in numeric format.

The interface for PEV charging provides a set of useful information to the users; however it is not geared toward persuasion in the same manner as the main dashboard and whole-house feedback are. The programmed charge panel provides some information on the outcomes of each charging alternative, but not in an easily comparative format.

Systems like Tendril, as enabling technologies, have a great potential to reduce PEV impact on the grid, which utilities have realized. Tendril CEO Adrian Tuck says that some utilities have agreed to give PEV owners a smart home system such as Tendril[1]. The main advantage of smart home systems is that they make it easy for PEV owners to adopt positive charging behaviour, which in turn makes the behaviour more likely. As Faruqui and Sergici (2010) found across a range of experiments they studied, "when time-of-use rates are accompanied with enabling technologies [such as two-way programmable communicating thermostats], the […] set of tariffs lead to a reduction in peak demand in the 27–44% range", as compared to the 13 to 20% drop when critical-peak pricing (CPP) tariffs were used alone.

Tendril is not the only company interested in offering information and control over PEV charging. Some smart charging stations (e.g. AV's and Blink's Smart Charging Station) also offer a more limited range of control and information through web portals. PEV manufacturers, such as Nissan and Toyota, are also interested in integrating their PEVs into smart grids and smart homes. Toyota is responsible for the Toyota Smart Center, which investigates Home Energy Management System (HEMS) equipped smart houses in order to adequately manage electricity. Figure 38 illustrates the ideal operation of the Toyota Smart Center system[2] presented in the company's website. However, further information regarding interfaces and feedback types was unavailable.

One limitation of Tendril's system as enabling technology, and potentially of all systems based on HEMSs, is that in the first stage they are mostly limited to residential charging. So far, to the extent that this survey could explore, there is no commercially available management system for PEV charging which integrates with public EVSEs for charge control or that acquires charging data directly from onboard computers.

A system being developed by IBM in partnership with EKZ (a Switzerland based utility) intends to overcome these limitations by connecting the management system directly with the PEVs. IBM program aims at connecting PEV systems and renewable energy production data to the cloud, in order to assist PEV owners in recharging their vehicles when green energy is available[3].

The information is presented to the user through a smartphone interface. The app

1. http://www.forbes.com/sites/amywestervelt/2012/01/24/bmw-rolls-out-ev-jumps-into-smart-homes-with-tendril/
2. http://www.toyota-global.com/innovation/smart_grid/
3. http://www.cnet.com/news/ibm-developing-ev-app-to-let-drivers-select-renewable-energy/

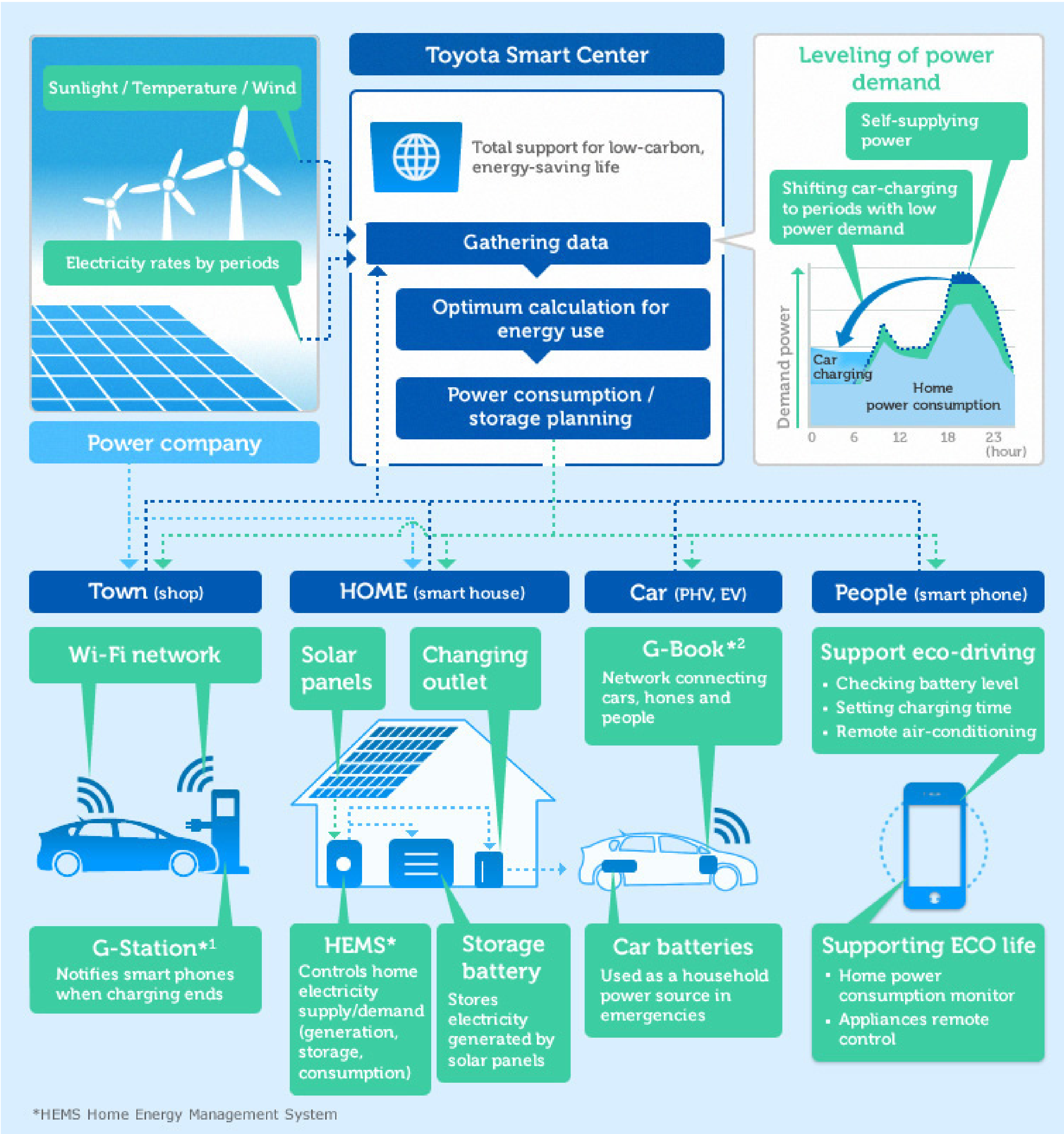


Figure 38. *Toyota Smart Center; source: Toyota website.*

informs when the most renewable electricity is being produced, based on real-time data from the utility, and allows the user to schedule PEV charging during those times. The data from the PEV is provided by a device installed in the vehicle (Fig. 39), which transmits the battery and charging information over the cellular network to IBM's cloud based system.

The pilot project, however, is mostly focused on the enabling technology for PEV and utility communication through IBM's cloud based system. The interface for the

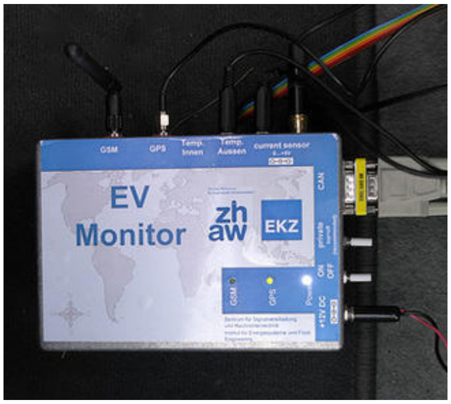


Figure 39. Monitor installed in PEV, by EZK and IBM.

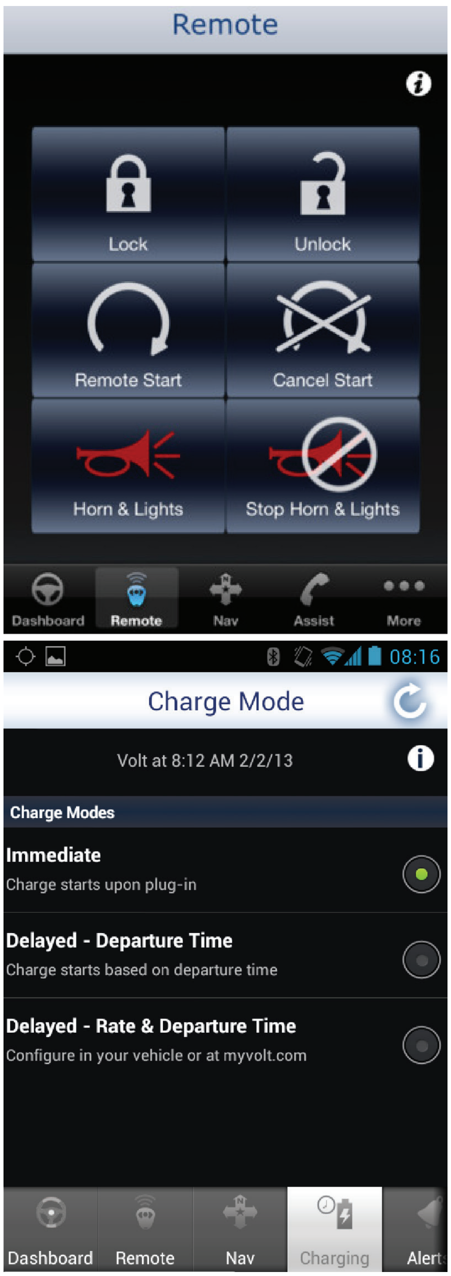


Figure 40. OnStar Remote Link - Chevy Volt app screens.

smartphone application presents lower levels of sophistication when compared to those observed in applications previously discussed. No strategy was detected to improve the effectiveness of information and nudge behaviour.

Smartphone apps also exist to interface directly with the PEVs. OnStar Remote Link apps are one example (fig. 40). According to the developer: "from your phone the Chevy Volt app lets you check your fuel economy, unlock your doors, remote start the climate controls, charge your car during off-peak rate times, and even monitor your tire pressure to optimize fuel economy".

For some of these systems reviewed, there is a relevant up-front cost (e.g. the purchase of smart charging stations) which might deter large scale adoption in the near future. However, as onboard systems allow remote control by the user, enabling technologies for PEV charging might become ubiquitous.

With regard to B. J. Fogg's analysis of persuasive technology, Personal Control devices can be classified as Tools, and therefore are primarily persuasive for making target behaviour easier for users to perform. In this sense, they can be already effective in improving PEV charging profiles per se. That is, they don't need to be designed around the goal of aligning PEV charging and non-dispatchable renewable availability to favor this goal. However we argue that further development of Personal Direct Control interfaces, taking into account specific persuasive strategies, could make them even more efficient.

B. J. Fogg (2002) suggests the following strategies for Tools to be persuasive: reduction, tunneling, suggestion, tailoring, self-monitoring, surveillance and conditioning. By applying reduction strategy, Personal Direct Control devices could make charging at ideal periods easier than at other periods. Similarly to Amazon's "one click purchase" system, Personal Control devices could have users being able to start charging with just one click when the period is ideal. Alternatively, it could also make charging at non-ideal periods more time consuming by increasing the number of steps necessary and even inflating the process with information on negative economic and environmental impact of bad charging habits.

By adopting tunnelling strategies, the Personal Direct Control device could lead the user through a charge programming process that favors best charging periods. Suggestion could prompt the use to charge at ideal periods at times it's more likely for the user to accept the suggestion (e. g. battery levels are not full and charging would not conflict with other activities). Tailoring and self-monitoring would make it more evident for the user the impacts of their charging habits. Surveillance, although controversial, could be effective by having users know that their charging habits can be accessed by a third person interested in green behaviour. Lastly, by adopting Conditioning, the interface could reward and praise the user for good behaviour.

Most of these strategies are not in use by Personal Direct Control devices, since they are not primarily designed to be persuasive or trigger green behaviour. Since this project is interested in persuasive interfaces, we believe that existing devices can become more effective towards our goal if the design is specifically conceived for such purpose.

	Indirect F.	Direct F.	Direct C.	A.S.	T.P.C.
Personal					
Home			●		
Work			●		
In-car					
Public					

5.8 Home and Work Direct Control

This category comprises Direct Control devices which are accessed in a specific spatially-localized apparatus. This survey did not identify systems specifically designed to address PEV charging, however examples for home energy management are plentiful. Figure 43 illustrates some of these examples, which could be adapted to address PEV charging as well.

The same considerations drawn for Personal Direct Control interfaces can also be applied to this category.

Figure 41. Examples of Home Direct Control devices for home energy management. In the left, Intel Home Energy display. In the right, Nest smart thermostat.

	Indirect F.	Direct F.	Direct C.	A.S.	T.P.C.
Personal					
Home					
Work					
In-car			●		
Public					

5.9 In-car Direct Control

In this category, onboard interfaces are expected to allow for features such as programmed charge which also accounts for financial and environmental aspects. However, this project could not identify such system in any surveyed vehicle.

We anticipate that In-car Direct Control interfaces will become much more relevant (eclipsing most other interfaces) when wireless charging turns ubiquitous. In such scenario, considerations drawn for Personal Direct Control interfaces should apply, jointly with considerations drawn for In-car Direct Feedback interfaces.

	Indirect F.	Direct F.	Direct C.	A.S.	T.P.C.
Personal					
Home				●	
Work				●	
In-car				●	
Public					

5.10 Home, Work and In-car Autonomous Systems

Because PEVs are not constantly plugged in or statically located like most smart appliances, their level of automation is intrinsically limited, forcing the user to engage in active charging behaviour. More widespread inclusion of PEVs in whole-home control system may happen when Vehicle-to-Grid or Vehicle-to-home systems are in place. These situations will require powerful management interfaces which are beyond the scope of this project. Completely automated charging systems may also become common when wireless charging networks are ubiquitous. Again, this scenario is beyond the scope outlined for this project.

	Indirect F.	Direct F.	Direct C.	A.S.	T.P.C.
Personal					
Home					
Work					
In-car					
Public					

5.11 Home Third Party Control

Currently, Third Party Control mostly comprises the concept of Utility Control Charging. As previously discussed, Third Party Control refers to the idea that the electric utility or a third party could have direct control over when PEV charging events occur. Some home management systems, such as Tendril's, have currently support for UCC.

Interfaces to integrate Third Party Control support is not the objective of this project. However, a later project might attempt to bring together feedback support and UCC support for an improved result.

FINAL REMARKS

This is part 1 of TIPSLab Project 006-003. As presented in the introduction, the sequent parts of this project will support, identify and develop ideal interfaces to be adopted in British Columbia for motivating positive charging behaviour.

The classification matrix as well as the devices' review presented in this document will serve as the basis for the following steps.

REFERENCES

Anderson, W. & White, V. (2009). "Exploring consumer preferences for home energy display functionality Report to the Energy Saving Trust," Design, no. August, 2009.

Ayres, I., Raseman, S., & Shih, A. (2012). Evidence from two large field experiments that peer comparison feedback can reduce residential energy usage. Journal of Law, Economics, and Organization, ews020.

Chitturi, Madhav V., and Rahim F. Benekohal. (2006). Effect of Speed Feedback Device on Speeds in Interstate Highway Work Zones. In Applications of Advanced Technology in Transportation. The Ninth International Conference.

Darby, S. (2001). Making it obvious: Designing feedback into energy consumption. In Proceedings of the 2nd international conference on energy efficiency in household appliances and lighting. Italian Association of Energy Economists/ECSAVE programme.

Ehrhardt-Martinez, K., Donnelly, K. A., & Laitner, S. (2010, June). Advanced metering initiatives and residential feedback programs: a meta-review for household electricity-saving opportunities. Washington, DC: American Council for an Energy-Efficient Economy.

EPRI. (2009). Residential electricity use feedback: A research synthesis and economic framework. Palo Alto: Electric Power Research Institute Report no. 1016844.

Faruqui, Sergici and Sharif. (2010). The impact of informational feedback on energy consumption—A survey of the experimental evidence," Energy, vol. 35, no. 4, pp. 1598–1608.

Faruqui, A., & Sergici, S. (2010). Household response to dynamic pricing of electricity: a survey of 15 experiments. Journal of Regulatory Economics, 38(2), 193-225.

Fogg, B. J. (2009). A behavior model for persuasive design. In Proceedings of the 4th international conference on persuasive technology, p. 40. ACM.

Fogg, B. J. (2002). Persuasive technology: using computers to change what we think and do. Ubiquity, 2002(December), 5.

ITF (2012). Electric Vehicles Revisited: Costs, Subsidies and Prospects, Philippe CRIST, International Transport Forum Discussion Paper No. 2012-3. Available at:

Jonn Axsen, Harry Joe Bailey and George Kamiya. The Canadian Plug-in Electric Vehicle Survey (CPEVS 2013): Anticipating Purchase, Use, and Grid Interactions in British Columbia. Technical Report. 2013.

Karlin, B., Ford, R., & Squiers, C. (2014). Energy feedback technology: a review and taxonomy of products and platforms. Energy Efficiency, 7(3), 377-399.

Morgan, T. (2012). Smart grids and electric vehicles: Made for each other?. International Transport Forum Discussion Paper.

Nolan, J. M., Schultz, P. W., Cialdini, R. B., Goldstein, N. J., & Griskevicius, V. (2008). Normative social influence is underdetected. Personality and social psychology bulletin, 34(7), 913-923.

Panneerselvam, P. J. (2013). Design of smart grid interfaces.

REVI Utilities Working Group (2012). EVs and Electric Utility Meters: A Discussion of Data Requirements and Options for Metering Electric Use by Plug-In Electric Vehicles. REVI Discussion Paper.

Schultz, P. W. (1999). Changing behavior with normative feedback interventions: A field experiment on curbside recycling. Basic and Applied Social Psychology, 21, 25-36.