Fuel electricity and plug-in electric vehicles in a low carbon fuel standard

Christopher Yang*
Institute of Transportation Studies, University of California Davis, Davis, California 95616, USA

HIGHLIGHTS

- The challenge for fuel electricity usage is vehicle demand, not fuel supply.
- LCFS will have a limited role in reducing fuel electricity carbon intensity.
- Carbon intensity will depend on regional, temporal and methodological factors.
- Policy design influences incentives between fuels and among electricity providers.

ABSTRACT

Electricity is unique among the alternative fuels in a low carbon fuel standard (LCFS) policy, in that demand from vehicles is the major barrier to its usage, not supply. This paper presents a policy discussion and policy recommendations on a number of topics related to the regulation and incentives for fuel electricity within the LCFS. In the near-term, the LCFS will have a limited role in incentivizing the use of electricity and lowering the carbon intensity of electricity, and electricity will play a small role in meeting LCFS targets. Calculating a carbon intensity value for electricity is a complex process, requiring many decisions and trade-offs to be made, including allocation methods, system boundaries, temporal resolution and how to treat electricity demand for vehicle charging. These choices along with other regulatory decisions about who can obtain LCFS credits will influence the incentives for providing electricity and charging infrastructure relative to other low-carbon fuels as well as across different electricity providers. The paper discusses how fuel electricity would fit into an LCFS, identifying those special characteristics that could reduce the effectiveness of the policy. It also provides specific recommendations to enable better policy design that appropriately incentivizes the use of low-carbon fuels.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

Electricity is one of the alternative fuels that are widely touted to help reduce greenhouse gas (GHG) emissions from the transportation sector (EPRI and NRDC, 2007; Samaras and Meisterling, 2008; NRC, 2009; Yang and McCollum, 2009; IEA, 2010). The low carbon fuel standard (LCFS), which regulates and incentivizes reductions in the carbon intensity (CI) of transportation fuels, is one of the key policies being discussed to reduce transportation GHG emissions. However, electricity has a number of important differences from other alternative, low-carbon fuels that can be used in the LCFS, and these differences require careful consideration from policymakers and regulators.

The purpose of this paper is to explore how fuel electricity will fit into an LCFS and present key issues of interest regarding policy incentives and regulatory decisions. This discussion is used to inform specific policy recommendations in order to ensure the policy adequately incentivizes electricity as a low-carbon fuel. Calculations based upon regional and national data are used to provide quantitative context for this policy discussion. Three sets of issues are discussed in this paper. The first is the value of electricity credits and the role electricity could play in LCFS compliance. The second relates to the determination of the
CI value for electricity and the factors that influence that value. The third highlights several key questions about electricity providers in an LCFS policy.

While the focus of this paper is an analysis of electricity within the LCFS, this focus is not meant to imply that electricity is the best way to meet an LCFS policy. Regulated parties must comply with the CI targets set forth by the regulation, and this analysis does not address the question of which fuel(s) should be used to reduce GHG emissions or comply with an LCFS policy. Regulated parties are free to choose whichever fuels they prefer and are not obligated to produce, supply or purchase fuel electricity. Instead, accurately and appropriately setting a regulatory CI value for electricity, including accounting for relative vehicle efficiency, will allow the market to decide which fuels and vehicle technologies will be used to comply with an LCFS.

Throughout this paper, the term “plug-in electric vehicles” (PEVs) is used to describe vehicles that use grid electricity to charge. PEVs can include plug-in hybrid electric vehicles (PHEVs), which can run on gasoline or electricity, and battery electric vehicles (BEVs), which run entirely on electricity. The term “fuel electricity” is used to differentiate electricity that is used as a transportation fuel from electricity that is used in more conventional applications.

2. Background and review of relevant concepts

2.1. Low carbon fuel standard

An LCFS is a policy that regulates the carbon content of transportation fuels in order to reduce GHG emissions associated with transportation activities. It is an important tool that develops a quantitative performance metric for transportation fuels based upon the fuel’s CI in order to incentivize reductions in GHG emissions (Farrell and Sperling, 2007; Sperling and Yeh, 2010). All fuels are given a regulatory CI value (grams of GHG per megajoule of fuel, or gCO₂e/MJ) accounting for the entire fuel production cycle in order to provide a fuel-neutral metric that can incentivize lower carbon fuels based upon their expected emission reductions relative to the gasoline baseline.

An LCFS policy has been implemented in California and is being discussed/proposed in several other jurisdictions (CARB, 2009a; NESCAUM, 2009; Andress and Nguyen, 2010; ORDEQ, 2010; TIAx, 2011). This analysis focuses on a hypothetical national LCFS policy, although many of its findings are also relevant to implementation at a regional level.

Under the LCFS policy, major oil providers and importers are the regulated parties that are required to reduce the CI of their fuel mix by the target amount. They can do so by reducing the emissions from the fuels they produce, changing their fuel mix, and/or purchasing credits on the trading market. Because electricity is not a traditional transportation fuel, electricity providers are not regulated parties in the LCFS. Fuel electricity providers may choose to participate in the credit trading market, where regulated parties purchase credits to aid in meeting their compliance target.

2.2. Electricity carbon intensity

There are numerous studies that have estimated or calculated the CI of electricity used to charge PEVs and assess their GHG impacts (e.g., EPRI and NRDC, 2007; Hadley and Tsvetkova, 2008; Samaras and Meisterling, 2008; NRC, 2009; McCarthy and Yang, 2010). Each of these analyses uses a different method for estimating the mix of power plants used to generate electricity to charge vehicles. This is due to the fact that there is no standardized method for calculating the CI of electricity for charging electric vehicles. The results of these analyses are quite variable because they were performed for different regions and different periods of time into the future and used different methodological approaches. But given the central importance of the CI value for the functioning of the LCFS, it is critical to understand how these regional, temporal and methodological factors can influence the calculation of electricity emissions.

2.3. Energy efficiency ratio (EER)

The energy efficiency ratio (EER) is an important tool for ensuring that fuels that lead to carbon reductions in transportation are appropriately incentivized in the LCFS. The EER is a factor that reduces the regulatory CI of a fuel based upon the vehicle’s improved efficiency (e.g., if a vehicle is three times as efficient as a baseline gasoline vehicle, then the CI of that vehicle’s fuel would be reduced by a factor of three). Electricity is a fuel that would not be adequately incentivized without the use of an EER, because the carbon savings are not reflected in the CI of electricity. The average CI for US average electricity in 2005 was nearly double that of gasoline on an energy basis (181 vs 93 gCO₂e/MJ), and its use would be disincentivized under the LCFS. However, using electricity as a transportation fuel would lower GHG emissions relative to a conventional vehicle running on gasoline because of the much higher vehicle efficiency (Kromer and Heywood, 2007; Plotkin and Singh, 2009), so an EER is used to lower the CI of electricity. In the California LCFS, the EER represents the relative efficiencies of drivetrains using the different fuels (compared on a miles-per-MJ basis) (CARB, 2009a, b). Fig. 1 shows that the value of the multiplier has a big impact on the regulated CI of electricity. An EER of 4 would make any electricity source favorable to gasoline, while for a multiplier of 3, all electricity sources except coal-steam power would be favorable to gasoline. An EER of 1, i.e., no efficiency adjustment, would effectively disincentivize the use of most electricity under the LCFS.

California chose a value of 3.0 for electricity based upon a comparison of equivalent gasoline and electric vehicles and adjusting for future fuel economy regulations (CARB, 2009a, b). Oregon did the same but proposed a declining value from 4.1 in 2012 to 3.1 by 2022 (ORDEQ, 2010). More recent data from EPA testing of the Nissan Leaf and Chevy Volt and current comparable gasoline vehicles yield EERs of 3.3 and 3.7 (Lutsey, 2011), which also leads to a value of around 3 when required near-term gasoline fuel economy improvements are factored in.

Note that for the remainder of the paper, all subsequent calculations and discussions of electricity CI will use an assumed EER value of 3.

3. Electricity and PEVs in the LCFS: Incentives and impacts

This section explores the incentives that the LCFS provides to fuel electricity as well as the potential contribution of electricity to LCFS compliance. Calculations and quantitative scenarios are used to help provide context for these discussions.

Because the principal goal of the LCFS is to incentivize the use of low-carbon fuels in the transportation sector, the emphasis of this section is to explore to what extent the LCFS incentivizes the use and CI reductions in fuel electricity, quantify the incentives it does provide and examine the potential for using electricity to achieve LCFS compliance. This discussion is not meant to identify ways for the LCFS to promote electricity over other fuels, but rather is meant to identify the barriers that prevent the LCFS from providing the equivalent incentives to electricity as with more conventional liquid low-carbon fuels.

Please cite this article as: Yang, C., Fuel electricity and plug-in electric vehicles in a low carbon fuel standard. Energy Policy (2012), http://dx.doi.org/10.1016/j.enpol.2012.05.006
3.1. Incentives for increasing electricity use in the LCFS

One of the key questions for fuel electricity is how the LCFS interacts with the current and expected future market and industry conditions for electricity and PEVs, so that it provides incentives to increase the use of fuel electricity as it does with other low-carbon fuels. Electric companies are not regulated parties, but the sale of fuel electricity will generate LCFS credits that could be purchased by regulated parties to meet their CI reduction targets. How the electricity providers use these credit trading revenues will influence the impact they have on the use of low-carbon fuels.

Electricity is already produced and sold in very large quantities for purposes other than transportation fuel, and using it as a transportation fuel requires the purchase of PEVs that store electricity from the power grid in batteries. Thus, the primary challenge of using electricity as a transportation fuel is not supply (i.e., the cost or availability of electricity) but rather the demand from electric vehicles (i.e., the amount of fuel electricity used will be dictated primarily by the number of PEVs in the fleet). Thus, if the LCFS is to have a significant impact on the use of fuel electricity, it will need to influence the fleet share of PEVs.

Given the high cost of PEVs (including the additional cost of home-based charging equipment), their adoption will be influenced most strongly by reductions in initial purchase price. PEVs are projected to have a higher capital cost than conventional gasoline-powered vehicles even with high-volume manufacturing; with large-scale production, these costs could be in the range of $3000–15,000 depending upon the size of the vehicle battery (Kromer and Heywood, 2007; Plotkin and Singh, 2009; Burke and Zhao, 2011). Additionally, the purchase and installation of home recharging equipment could add several thousand dollars to the initial investment for a PEV driver (NRC, 2009). Because of the efficiency of electric drive and the cost of electricity, drivers will have significantly lower fuel costs per mile of travel, by a factor of two to four. However, consumers appear to exhibit very high discount rates when it comes to weighing purchase price of a vehicle versus fuel cost savings for more efficient vehicles (Greene, 2010; Gallagher and Muehlegger, 2011).

3.1.1. LCFS credit market and value of electricity

This section explores the potential value of LCFS credits for low-carbon electricity. Quantitative values are presented to provide context for the discussion of revenues of to electricity providers and the potential for stimulating PEV adoption.

The revenues for electricity in an LCFS credit trading market are dependent upon the regulated CI of the electricity and the carbon trading price in $/t of CO2 displaced. In a national market, there would be one fuel that sets the market-clearing credit price for the LCFS trading, which would be determined by the marginal (i.e., most expensive from a CI reduction standpoint) fuel that is used to satisfy the regulation. Low-carbon fuels can be arranged as a supply curve, with various fuels having different prices per ton of reduction relative to gasoline. Given the expected prices for biofuels and other alternative fuels (CARB, 2009a), electricity will be at the low end of the supply curve but would be able to command the market-clearing price for its carbon reductions.

The value of LCFS credits for electricity ($/kWh) is calculated using equation

\[
V_{\text{elec\_credit}} = (C_{\text{gasoline}} - C_{\text{elec}})(EER_{\text{elec}})P_{\text{permit}}
\]

where \(C_x\) is the regulated CI of fuel \(x\), \(EER_{\text{elec}}\) is the adjustment factor for electricity and \(P_{\text{permit}}\) is the market price of carbon on the LCFS trading market. Fig. 2 shows the credit value on a per-unit (kWh) basis as a function of the cost of carbon permits and the CI of electricity, and the value of permits is in the range of the cost of electricity (nationally, electricity prices range from $0.06 to $0.20/kWh, with an average of $0.10/kWh).

At a permit price of $100/t CO2 and US average electricity, LCFS revenues for electricity would be around $0.035/kWh, which would be a substantial fraction of total electricity cost. At higher permit prices and in regions with clean electricity, the LCFS revenues would match or exceed the cost of electricity.

Fig. 3 shows the annual total revenue that an electricity provider could expect to generate from the sale of credits for the electricity being provided to charge one BEV (3600 kWh/yr assuming 12,000 miles/yr at 0.3 kWh/mile). The value in the figure would be correspondingly lower for charging a PHEV40 or PHEV10 by a factor of 60% and 20%, which is the estimated...
proportion of driving powered by electricity (i.e., utility factor), based upon household travel data (Kromer and Heywood, 2007). This figure indicates that for a permit price of $100/t, an electricity provider that has an average electricity CI value (e.g., 656 g/kWh or 61 g/MJ) could obtain around $125 per BEV/yr or $75 per PHEV40/yr. A permit price of $200/t and cleaner electricity (300 g/kWh or 28 g/MJ) could obtain around $500 per BEV/yr or $300 per PHEV40/yr.

These revenues that accrue to electricity providers from LCFS credit trading could be used in many different ways, such as using all or a portion of the value for subsidizing the price of fuel electricity, providing a purchase incentive to PEV buyers, funding public or private vehicle recharging infrastructure, or upgrading electricity generation, transmission or distribution or other measures that reduce costs or improve the utility of PEVs. However, it is not guaranteed that the recipient will reinvest these revenues in a way that furthers the goals of the LCFS. The recipients of the LCFS trading credit will need to decide, dependent upon their business model, how to use these revenues that they may accrue, especially in light of the uncertainty in future credit values and
revenues. However, a direct consumer PEV purchase incentive appears to be the most effective means of increasing the number of PEVs on the road, and the primary policy mechanisms that are being discussed and used to increase adoption of PEVs focus on reducing the purchase price for consumers, such as direct subsidies, tax credits, and feebates.

A potential barrier to providing a substantial incentive at the time of vehicle purchase is that credit revenues will accrue as an uncertain future stream of revenue (tens of hundreds of dollars per year) that comes from the usage of a vehicle over its lifetime. The permit price would likely fluctuate as the stringency of the target and the cost and supply of various alternative fuels changed over time. The electricity provider would also need to guarantee that the PEV driver would recharge primarily through that provider in order to ensure a continued revenue stream of future LCFS credits. This arrangement could make the most sense for providers of home-based recharging equipment, as the majority of PEV charging is likely to occur at home.

3.1.2. Non-LCFS PEV and fuel electricity incentives

Ideally, the revenues from LCFS credit generation would be used to encourage the further use of low-carbon electricity. Since electricity is already widely produced and distributed, credit generation could occur even without specific investment in the provision of fuel electricity (i.e., charging infrastructure deployment). Instead, revenue from LCFS credit trading could represent a windfall for electricity providers, such as utilities, if consumers purchase PEVs due to other PEV incentives or personal preferences and the credit revenues are not used in a way that promotes additional fuel electricity usage.

Even if LCFS incentives are directed to encouraging PEV adoption, it will be difficult to quantify their incremental impact, given the multitude of other PEV incentives, many of which are larger and more direct than the LCFS, e.g., the $7500 federal tax credit. Table 1 lists a number of existing and proposed direct and indirect policies to incentivize PEVs.

Even if LCFS incentives are directed to encouraging PEV adoption, it will be difficult to quantify their incremental impact, given the multitude of other PEV incentives, many of which are larger and more direct than the LCFS, e.g., the $7500 federal tax credit. Table 1 lists a number of existing and proposed direct and indirect policies to incentivize PEVs.

3.2. Incentivizing reductions in electricity carbon intensity

Another important question about an LCFS is the extent to which it incentivizes further reductions in CI of electricity, beyond the switch from gasoline to electricity.

Parties regulated under the LCFS will generally have direct incentives to use lower carbon resources and processes in their fuel supply chain. In the case of electricity, there may be a disconnect if the electricity provider has little or no influence on the regulatory fuel CI (e.g., if the electricity provider is a third-party charging provider) or if the region used for determining CI is much larger than the utility service territory.

Electricity CI may be calculated in the LCFS at the load balancing area or higher level of aggregation (encompassing dozens or more investor-owned and municipal utilities). California, for example, is calculating one CI value for the entire state. While large regional aggregations make sense based upon the nature of power system grid operation and dispatch, changes that one entity may make to lower emissions from its mix of generation will have a relatively small impact in terms of the CI of the larger region, reducing the incentive to make changes based upon benefits that may accrue from the LCFS.

Additionally, the amount of electricity used for charging PEVs will be quite small relative to total electricity sales for several decades. Thus, even electricity providers that have the ability to alter their generation mix are unlikely to make significant changes to that mix just to gain some additional revenue associated with a small portion of overall electricity sales.

One way in which the LCFS could have a significant influence on the CI of fuel electricity is if PEV charging could be contractually linked to lower-carbon electricity generation (e.g., through renewable energy certificates, or RECs). This could enable LCFS credit revenue to finance generation from low-carbon resources (which would in turn increase the value of the LCFS credits that would be generated). Low- or zero-carbon electricity would also be a compelling incentive for many PEV drivers. However, given the current availability of low-carbon electricity in the grid mix, appropriate regulatory restrictions need to first be put into place in order to ensure that this practice leads to additional low-carbon generation rather than to shuffling of existing electricity resources.

Because electricity generation is a large contributor to GHG emissions, there are already existing or proposed incentives and policies that target electricity sector emissions in many states, including renewable portfolio standards (RPS), as well as economy-wide carbon policies (such as cap-and-trade). These will likely play a much larger role in decarbonizing electricity than an LCFS.

3.3. The role of PEVs in near-term LCFS compliance

In order to quantify and understand the potential role that PEVs and fuel electricity could play in helping to achieve LCFS compliance, two scenarios for PEV fleet growth were developed. These adoption scenarios are not meant to reflect the impact of the LCFS on PEV adoption. Rather, they are scenarios that could unfold due to the many other policies incentivizing PEVs (see Table 1), independent of the LCFS. There are a large number of different PEV adoption scenarios (EPRI and NRDC, 2007; CARB,)

---

Table 1
List of existing and proposed policies to incentivize PEVs and fuel electricity use (DOE, 2012).

<table>
<thead>
<tr>
<th>Consumers</th>
<th>Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle purchase</td>
<td>Vehicle purchase incentives (tax benefits, rebates, feebates)</td>
</tr>
<tr>
<td></td>
<td>Preferential parking or carpool lane access</td>
</tr>
<tr>
<td>Fuel provision and charging infrastructure</td>
<td>Charging equipment purchase incentives (tax benefits and rebates)</td>
</tr>
<tr>
<td></td>
<td>Fuel electricity subsidies</td>
</tr>
<tr>
<td>Reducing CI of electricity supply</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Technology mandates (i.e., ZEV mandate)</td>
</tr>
<tr>
<td></td>
<td>Vehicle fuel economy and GHG standards</td>
</tr>
<tr>
<td></td>
<td>R&amp;D</td>
</tr>
<tr>
<td></td>
<td>Manufacturing loans or tax incentives</td>
</tr>
<tr>
<td></td>
<td>Fuel performance standard</td>
</tr>
<tr>
<td></td>
<td>Improve installation process (permitting, inspection)</td>
</tr>
<tr>
<td></td>
<td>Building codes that require &quot;charger&quot;-ready wiring on new construction</td>
</tr>
<tr>
<td></td>
<td>Carbon taxes, cap and trade</td>
</tr>
<tr>
<td></td>
<td>Renewable portfolio standards</td>
</tr>
</tbody>
</table>

Please cite this article as: Yang, C., Fuel electricity and plug-in electric vehicles in a low carbon fuel standard. Energy Policy (2012), http://dx.doi.org/10.1016/j.enpol.2012.05.006
2009a, b, c; NRC, 2009; EIA, 2010; McCarthy and Turrentine, 2010; Leighty, 2012) that range from conservative to extremely optimistic. The two scenarios presented here are based, in part, on scenarios of PEV adoption from the California Air Resources Board (CARB, 2009c) and the National Research Council’s PHEV report (NRC, 2009). They are not projections of the most likely adoption of PEVs, but instead they are meant to demonstrate a reasonably optimistic case and a very optimistic upper bound on the impact of PEVs on CI reduction.

Table 2 shows the assumptions for these two scenarios as well as the results of the calculation of the contribution of electricity to the fleet CI reduction, resulting from the efficiency improvement due to the fraction of PEVs in the fleet, the fraction of their miles running on electricity, and the regulated CI of the electricity that is used to charge the PEVs.

The number of PEVs in the Less Aggressive scenario was based upon the NRC’s “Probable” fleet trajectory, while the Aggressive scenario was built based upon an analysis by the CARB and assumes that much of the country follows California’s lead in adopting PEVs. Both of these scenarios have significantly more PEVs than the AEO, which assumes only about 3.3 million PEVs in the fleet in 2030 (about 1% of the total fleet) (EIA, 2010). Both scenarios assume that significant improvements in vehicle technology, cost reductions and substantial policy intervention occur for PEVs to achieve the adoption levels in these scenarios.

The key takeaways from this calculation (shown in Table 2) are that with optimistic assumptions about PEV adoption and electricity CI (e.g., the Aggressive case), PEVs could make a substantial contribution to LCFS compliance (reducing overall fleet CI, the average CI of all fuels used for light-duty vehicles, by 1.4% in 2023 and 5.9% in 2030). However, in the Less Aggressive scenario (which is arguably still fairly optimistic), the contribution is quite small (reducing fleet CI by only 0.7% in 2030). With a target of 15% reduction in fleet CI by 2030, the bulk of LCFS compliance will need to come from other sources in the near to medium term, due to the challenge of ramping up PEV fleet share in the next decade or two. This shows that PEVs and fuel electricity could have a small to moderate impact on near-term LCFS compliance. Assuming continued growth in PEV penetration, the contribution of electricity to LCFS compliance could continue to grow.

Table 2 also shows an estimate of the LCFS credit revenue per vehicle per year at two different CO2 permit prices for 2030. At a permit price of $100/t CO2e, the two scenarios have revenues of $64 and $157 per PEV per year. This value, even if given entirely to PEV drivers, is a small fraction of the total incremental cost of purchasing a PEV (Kromer and Heywood, 2007; Plotkin and Singh, 2009; Burke and Zhao, 2011).

While the revenue and fleet CI reduction values are averages for the US as a whole, they could vary dramatically across different regions. In those areas with greater PEV penetration and lower-than-average electricity CI, PEVs would have larger revenues associated with them and would be responsible for a greater proportion of the reductions in fleet CI.

4. Setting a carbon intensity of electricity

The CI is the most important number in the LCFS because it is the metric for comparing GHG reduction potential across different fuel types. Thus, setting the CI value for electricity is an important process. However, electricity analysis is a complex process, and there is no standardized method for calculating the CI of electricity (Curran and Mann, 2005). Thus, the choice of methods and approaches that are used to calculate CI will influence the CI value and the incentives given to fuel electricity relative to other low-carbon fuels.

Table 3 shows a list of key choices and factors that influence the calculation of electricity CI. While several datasets provide information about individual power plant and regional electricity emissions (EPA, 2007; EIA, 2010, 2011), they include only direct plant combustion emissions rather than the full life-cycle emissions. Life-cycle analyses (such as the GREET model) provide estimates for the additional (i.e., “upstream”) emissions (primarily associated with feedstock extraction and transport) associated with supplying electricity from different types of power plants (Wang, 2010). Adding these generic upstream emissions (see Table 4) to the power plant-specific values given in these databases is critical for making...
Table 4

<table>
<thead>
<tr>
<th></th>
<th>Direct Combustion Emissions (CO2ₑDC)</th>
<th>Upstream Emissions (CO2ₑUP)</th>
<th>CO2ₑUP/CO2ₑDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal steam</td>
<td>1180</td>
<td>55</td>
<td>4.7%</td>
</tr>
<tr>
<td>Oil fired</td>
<td>906</td>
<td>126</td>
<td>13.0%</td>
</tr>
<tr>
<td>Coal IGCC</td>
<td>874</td>
<td>51</td>
<td>5.8%</td>
</tr>
<tr>
<td>NG combustion</td>
<td>665</td>
<td>114</td>
<td>17.2%</td>
</tr>
<tr>
<td>NG combined</td>
<td>415</td>
<td>72</td>
<td>17.2%</td>
</tr>
<tr>
<td>cycle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass fired</td>
<td>0</td>
<td>116</td>
<td>–</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0</td>
<td>15</td>
<td>–</td>
</tr>
<tr>
<td>Geothermal</td>
<td>0</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>Wind</td>
<td>0</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>Solar</td>
<td>0</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

accurate comparisons of the full fuel-cycle impacts of the adoption and use of transportation fuels.

4.2. EER revisited

As described in Section 2.3, the EER adjustment factor has an enormous impact on the regulated CI of electricity. Since the EER can be calculated in a number of ways, modifications and refinements to the calculation method will influence the incentives for electricity.

Several regions have decided to implement the EER based upon equivalent vehicles (CARB, 2009a,b; ORDEQ, 2010). However, assessing equivalence between PEVs and conventional gasoline vehicles can be challenging because so many attributes (e.g., size, range, power, acceleration) can differ.

The efficiency multiplier could be calculated based upon the average vehicles using each fuel or the newest, best and most efficient vehicles using the respective fuels (i.e., comparing PEVs to the average gasoline vehicle in the fleet or a new hybrid vehicle in the same class). An efficiency multiplier based upon fleet averages would reflect how the fuels, on average, are actually used, while the EER based upon equivalent vehicles would be more reflective of the relative technical efficiency of the respective drivetrains.

Regardless of which approach is taken, the EER is likely to change over time as the underlying drivetrain technologies improve and vehicles in the fleet mix change. It is important to periodically revisit the regulated EER value for PEVs and other alternative drivetrains so that they accurately reflect the state of vehicle technologies over time. It is likely that the EER for vehicles using electricity would decline somewhat over time, to around 2.5, because of the greater improvement potential for gasoline vehicles related to internal combustion engine (ICE) engine and drivetrain efficiency improvements (e.g., hybridization) (Lutsey, 2011).

4.3. Allocation method

A regional electricity grid consists of a large number of diverse generation sources and numerous electricity loads, with a large, complex, interconnected transmission and distribution system serving to match supply and demand in real time. Given the complexity, it is impossible to match up loads with electricity generated in a specific power plant. Instead, simplifying assumptions are made in order to assign or allocate specific power plants to specific loads, and there are multiple methods for performing this allocation process. There is no one “correct” method for this assignment, as there is no means to verify or evaluate the results.

Instead, the method of allocation is a choice to be made by the analyst/regulator and requires balancing a number of trade-offs between data availability and modeling requirements (detailed monitoring, system modeling vs estimated average), incentives that policy makers wish to provide, and differing points of view about the how vehicle charging emissions should be treated.

One of the most fundamental questions in choosing a method is how to treat the demand from vehicles. If vehicles are viewed as equivalent to any other electricity demand on the system, electricity and emissions representing the average grid mix will be used. However, if vehicles are being treated as a separate class of demand that is being imposed on the electricity grid, then marginal electricity generation and emissions will be assigned to vehicles. The rationale for the marginal approach is that policy makers and analysts want to understand the consequences of policies or decisions that increase the use of electricity as a fuel, and understanding the resulting change in emissions is important. The distinction between these approaches is important, as there can be large differences between the average and marginal CI values. In California, marginal emissions in 2020 are estimated to be 73–95% higher than average emissions depending upon the timing of PEV charging (Assen and Kurani, 2011).

In addition to this question of average versus marginal emissions, a number of additional choices need to be made in order to specify an allocation method for electricity emissions, all of which can affect the value of CI.

4.4. Temporal considerations

The temporal resolution in calculating CI is important because generation mix and PEV charging will vary over the course of a day and seasonally. An approach with high temporal resolution allows for a calculation that takes into account the coincidence between PEV charging and generation mix (including the availability of intermittent renewable generation). However, this approach requires the availability of high-resolution (e.g., hourly) data or detailed grid modeling. Also important is whether electricity CI is calculated retrospectively (ex post) for a past time period or is estimated prospectively (ex ante) for a current or future time period.

If a marginal (i.e., consequential) approach is to be used, the timeframe of the analysis is important. The question being asked for a marginal or consequential analysis is “what is the change in emissions that results from adding PEV charging demand to the electricity grid?” A short-term focus would restrict the building of new power plants, so the addition of PEV recharging demands would simply affect the operation of existing power plants in the system. A longer-term focus would also allow for changes in the mix of installed power plant capacity that serves electricity demands. This distinction is important when one is considering whether intermittent renewables can be on the margin. Intermittent renewables are not controllable and have low operating costs and so are generally dispatched first. With a short-term focus, they would not be on the margin. However, with a longer-term analysis, adding PEVs to a power system with a RPS, could lead to additional (i.e., marginal) use of renewables.

4.5. Regional factors

Electricity systems in the US are extremely heterogeneous and regionally specific. Determining the regional CI of electricity requires a definition of the regional system boundaries, and one of the main challenges in defining regional electricity emissions is accounting for cross-border power flows (Jusko, 2006; Weber and Jaramillo, 2010). Fig. 4 shows several commonly used boundaries for electricity analysis in the US. Currently, there is no requirement to track the source and emissions of these cross-boundary flows, which makes it...
difficult to assess regional emissions (Alvarado and Griffin, 2007).
Instituting a tracking system would benefit all electricity systems
and enable much more accurate emissions calculations.

The CI of electricity will vary across regions due to differences
in the mix of power plant capacity, and primary energy and
renewable resources within an electricity region, as well as how
those resources are managed and utilized in order to meet the
demand for electricity. There is significant variation around the
US average electricity CI (see Fig. 5).

In addition, the size of regional aggregations affects the
variability in CI between regions (see Fig. 6). There is significantly
greater spread in average CI when we look at the 112 eGRID
power control areas (PCA) compared to the 10 NERC regions. Each
of these regional aggregation levels is larger than the service
territory for an individual electricity service provider (utility or
other load-serving entity). If the assigned CI value is the same for
all electricity providers in a specified region, this reduces the
incentive for electricity providers to make investments that lower
the CI of their electricity mix. Larger regions provide more
uniform incentives to all electricity providers, while smaller
spatial boundaries would lead to greater variability of electricity
CI and differential incentives in different parts of the country.

4.6. Default values and opt-in

Instead of accepting the regulatory (i.e., default) CI value for
the electricity region, some electricity providers may want to
propose using CI values specific to their company (i.e., opt-in).
There can be two types of opt-in, categorized here as informational and contractual. In one form of opt-in (“informational”),
entities have analyzed their generation, spot market purchases
and import/export mix and have calculated their own CI value.
If this value is lower than the default value for that region, they
can receive greater revenue from credit trading with the lower
CI value. However, opt-in values for electricity are more
complicated than for other alternative fuels. Default values
for most fuels in the LCFS are based upon technical representa-
tion of the energy inputs and emissions for a generic pathway,
while the default values for electricity in the LCFS should be
calculated for the specified power region based upon the
generation mix and electricity demands from all electricity
providers in that region. Ability to opt-in would presumably
lead to adverse selection, since only providers with lower CI
than the default value would choose to do so. Opt-in would
change the composition of the remaining region’s supply and
demand and should lead to the calculation of a new, higher
regional default CI value.

In a second form of opt-in (“contractual”), an electricity
provider purchases low-carbon electricity specifically for vehicle
charging. Since electricity for charging PEVs is a small fraction of
the total electricity demand, shuffling of generation sources to
supply low-carbon electricity to PEVs is an important concern,
and the additionality of the renewable or lower-carbon genera-
tion would need to be verified.

Please cite this article as: Yang, C., Fuel electricity and plug-in electric vehicles in a low carbon fuel standard. Energy Policy (2012), hhttp://dx.doi.org/10.1016/j.enpol.2012.05.006
4.7. Choosing a method to calculate CI

Choosing a method to calculate the electricity CI will require a choice to be made on a number of the issues discussed. The decisions will be made after consideration of the appropriate levels of complexity, transparency and consistency in regulation and policy design. The complexity and transparency of regulatory implementation will depend upon the availability of data resources. For consistency, similar allocation methods should be used across all fuels and over time. Unfortunately, no one allocation method can simultaneously meet all of these criteria. An average approach aids in simplicity and transparency because calculations can be based upon aggregate data and consistent with detailed, engineering-based CI calculations for most fuels. The marginal (i.e., consequential) approach is a more accurate assessment of the additional emissions from adding PEVs to the grid and is consistent with the approach for calculating the impact of market-mediated processes (e.g., the indirect land use change (iLUC) emissions for biofuels).

5. Point-of-regulation considerations

This section discusses several important considerations related to how the point of regulation and associated regulated parties...
may be defined for fuel electricity under an LCFS policy. It is important to highlight these issues so that an effective policy can be designed that acknowledges the unique aspects of the provision of PEV charging relative to other fuels while not impeding the development of a competitive fuel electricity market. Part of the challenge with regulation in the PEV vehicle, charging and electricity provider space is that this is a nascent and rapidly changing market. These markets and business models are expected to look quite different in a few years, and it is critical that any regulations not impede or adversely affect the evolution of this market. Metering, billing, providing access to charging and other essential aspects are still being developed.

5.1. Who can obtain the LCFS electricity credits?

Parties that provide electricity will likely not be automatically regulated under the LCFS (CARB, 2009a; ORDEQ, 2010). As a result, there is no obligation for electricity providers to provide electricity to PEVs or, even if they do, to comply with LCFS targets. However, it is presumed that electricity providers would participate in LCFS credit trading because of the associated revenues. Regulated parties (i.e., traditional fuel providers) could then purchase these credits to aid in their company’s compliance. A central question for the LCFS is who will obtain the LCFS credit for providing fuel electricity. There are several parties in the chain of providing electricity to the vehicle battery, including the power plant operator, the utility that aggregates power flows and operates of the transmission system to meet customer demands, the charging device owner and the driver who recharges. Any of these parties could potentially obtain the LCFS credit, depending upon how the policy is designed. Under the California LCFS, load-serving entities (i.e., utilities and municipal electricity providers) and third-party providers would likely be the two primary recipients of the credit. Third parties could be local governments, organizations or businesses that want to provide vehicle recharging infrastructure or service to its constituents, employees or customers. It will be up to the policy design to lay out who may be able to obtain the financial benefits from the LCFS associated with recharging PEVs.

Utilities are a logical choice for obtaining the credit, especially since they are responsible for procuring electricity and providing it to their customers and have metering and billing systems for data reporting. However, because supplying electricity to PEVs will be a small part of the utility’s business and utilities are generally highly regulated, they may not have an incentive or even the ability to spend revenue from the LCFS to provide infrastructure to a small segment of their customer base (Suetake, 2009). With over 3000 distinct utilities in the US with different business models and governing regulatory bodies, e.g., public utilities commissions, there could be a range of outcomes in terms of how much these LCFS credit revenues are used to increase the use of low-carbon fuels.

Another approach is to make the PEV charging equipment owners the recipient of the credit, since they are providing the actual point of refueling. Since most all PEV charging will likely occur at a charger, it provides a consistent point of regulation. It also provides a means for requiring appropriate metering and reporting requirements for charging equipment in order to obtain credits. Rules may be needed to prevent unfair competition between third-party charging equipment suppliers and utilities, which may be able to spread costs over a large pool of non-PEV customers. This approach brings up the question of who would obtain the LCFS credits for charging equipment owned by the PEV driver. It is not clear that a market can and should accommodate thousands or millions of individual small credit traders and transactions. One solution would be to allow PEV owners who own their charging equipment to sign away credit generation to a third-party credit aggregator that, in return, provides an annual check or subsidizes the equipment, vehicles or fuel purchases.

From a policy maker perspective, one approach to deciding who can claim LCFS credits is to consider who is likely to use the proceeds from the sale of credits in a manner that will enhance the goals of the LCFS, i.e., lowering the fuel CI and increasing the amount of alternative fuels being consumed. Increased infrastructure deployment can increase the amount of fuel electricity used by spurring additional PEV sales and increasing charging opportunities for existing PEV drivers. Some have argued that smaller third-party providers may influence the PEV market more than utilities would, because third-party charging providers would receive LCFS credits only if they deployed useful charging infrastructure that is used by PEV drivers, whereas utilities could obtain LCFS credits simply by virtue of having customers who purchase PEVs (Kahl and Lindl, 2009; Lowenthal and Quinn, 2009). Utilities could also participate by installing charging equipment and putting rules in place to prevent unfair competition. Allowing the infrastructure provider to obtain the LCFS credit, rather than simply defaulting to the electric utility, potentially increases the level of investment that results in useful infrastructure or direct subsidy to PEV purchasers.

5.2. Are electricity providers regulated as public utilities?

Providing electricity to charge PEVs brings up the important question of who is allowed to sell electricity. The regulatory environment for utilities differs greatly around the country such that in some places, providers who “sell” electricity to consumers could be regulated as public utilities, which could restrict charging infrastructure deployment to utilities and other load-serving entities. Several different business models are being developed to sidestep these restrictions, including selling “access” to the charger or parking at a spot with a PEV charger, based upon time rather than the amount of electricity used, or selling a monthly subscription for access to a network of charging stations. However, because public utilities are so highly regulated, regulating third-party charging providers as public utilities would prevent their involvement in the provision of charging infrastructure, could restrict competition, innovation and deployment of widespread public infrastructure, and could reduce the use of electricity as a fuel (CPUC, 2009).

The California Public Utilities Commission (CPUC) recently decided that companies that sell vehicle recharging services would not be regulated as public utilities, but an important question for a national LCFS is whether or not a similar process will need to take place in each state or regional public utilities bodies or whether a national policy can and should preempt this local review process (CPUC, 2010).

5.3. Tracking and reporting electricity use from PEVs

Unlike conventional fuel sales with a dedicated pump, it can be difficult to determine how much electricity is used for charging PEVs since most electricity is used for non-PEV purposes and not all near-term PEV charging will be separately metered. Since PEV chargers are now being built with utility-grade meters, it makes sense to tie the generation of LCFS credits to requirements on electricity providers to supply regulators with verifiable, metered data and detailed PEV charging timing profiles that can be used for utility planning and CI calculations.

The market for PEV chargers is emerging, so there will be a great deal of innovation in the arena of metering and billing for PEVs in the coming decades, with more widespread use of PEV chargers and dedicated submeters, and improvements in the
ability to track PEV charging. While it may be necessary to wait until these systems mature before robust regulations on monitoring can be implemented for PEV charging, LCFS requirements for metering and reporting for the purposes of credit generation may accelerate these changes.

6. Policy discussion conclusions and recommendations

Electricity is unlike other fuels that will be used for compliance in an LCFS, primarily because the key barrier to its use as a transportation fuel is due to the challenge of increasing plug-in electric vehicle demand rather than increasing supply. This distinction from other alternative fuels means that incentives for increasing fuel use are different and special consideration should be given during policy design to ensure that the use of electricity is treated appropriately and equivalently to other fuels such that the market can decide which fuels are used to comply with the LCFS. The primary purpose of this paper is to present a policy discussion of how fuel electricity and PEVs would fare under an LCFS given these unique characteristics and to discuss how to address any potential disparities in how electricity is treated in order to make the LCFS a more effective policy.

Based upon this discussion, several policy recommendations are presented to promote two primary goals: (1) as with other fuels, revenues generated by electricity from LCFS trading should incentivize the production and use of additional low-carbon fuels (i.e., fuel electricity) and reductions in the CI of those fuels and (2) electricity CI should be calculated in a simple, transparent and consistent manner. A secondary goal is to ensure that the LCFS does not hinder the development of a competitive and robust fuel electricity ecosystem.

6.1. Policy discussion highlights and conclusions

In order for the GHG benefits of fuel electricity (via PEVs) to be incentivized under the LCFS, an EER needs to be applied in order to lower the CI of electricity.

An LCFS will provide an incentive to increase the use of fuel electricity primarily if it induces additional PEV sales. However, even the most direct approach, applying revenues from the sale of LCFS credits toward increasing PEV sales, will likely have a relatively small impact compared to other existing PEV incentives.

The LCFS will play a small role in reducing the near-term CI of electricity since PEV charging will compose a small fraction of total electricity demand and electricity CI is likely to be set at a regional scale that encompasses many electricity providers. One way the LCFS could contribute is by providing a mechanism for enabling contractual linking of low-carbon or renewable generation directly to PEV charging and ensuring the additionality of that generation.

In the near term (the next two decades), PEV adoption will be a small fraction of the total light-duty vehicle fleet, and thus electricity would contribute a small amount to LCFS compliance (up to a 6% reduction in fleet CI by 2030, but potentially much lower).

The value of LCFS credits to electricity providers will depend upon their electricity CI, the EER and the permit trading price ($/t CO₂), which will be set by the marginal fuel used to meet the regulation. Revenues from the sale of LCFS credits from providing fuel electricity to PEVs could amount to one to several hundred dollars per year per BEV.

Calculating the regulated CI of electricity is important because it determines the value of electricity relative to other low-carbon fuels in the LCFS. However, there is no standard method for doing so, and it is a complex process involving numerous decisions to be made, including the choice of an allocation method (average vs. marginal), regional boundaries, and temporal resolution. These choices will depend upon the goals of the policy maker and the availability of data, but all methods involve trade-offs with respect to simplicity, transparency, consistency and accuracy. The choices made will also influence the incentives for electricity providers relative to other electricity providers in different regions and other fuel providers.

Allowing electricity providers to specify their own CI distinct from the default, regional electricity CI raises some challenges that need to be addressed. Informational opt-in, in which an electricity provider provides verification that its generation mix is cleaner than the regional CI, is prone to adverse selection and requires recalculation of the default CI. Contractual opt-in, where a provider purchases power from a specific source, is more straightforward, but additionality of low carbon generation should be verified to prevent shuffling within existing generation.

6.2. Policy recommendations

The policy should encourage the reinvestment of LCFS trading credits toward LCFS goals, i.e., lowering the CI of fuels and/or increasing the use of low-carbon fuels. One mechanism for furthering the use of fuel electricity under the LCFS is to tie the generation of credits to the owner of charging equipment (which could include utilities and third parties). This would lead to greater investment in charging infrastructure from a wide range of parties, enhancing utility to current and potential PEV drivers. Aggregation of credits that would accrue to driver-owned charging equipment could result in substitution of home-based chargers.

Electricity providers that provide PEV charging services should not be regulated as public utilities. Reducing the level of regulation will promote innovation in PEV charging and enable greater deployment of public infrastructure.

In order to obtain LCFS credits, electricity providers should be required to provide detailed data on charging load, timing and location by a verifiable, utility-grade meter. This information will be used for grid planning and CI calculations and also ensure that PEV charging does not cause or exacerbate grid issues.

Acknowledgments

The author would like to acknowledge support from the sponsors of the National LCFS Study, the Energy Foundation, and the William and Flora Hewlett Foundation, as well as the University of California, Davis and the Sustainable Transportation Energy Pathways (STEPS) program within the Institute of Transportation Studies. The author would also like to thank Dan Sperling, Jamie Rhodes, Sonia Yeh, other project members, key stakeholders and the anonymous reviewers for their excellent feedback and comments, which have helped improve this work.

References


Please cite this article as: Yang, C., Fuel electricity and plug-in electric vehicles in a low carbon fuel standard. Energy Policy (2012), http://dx.doi.org/10.1016/j.enpol.2012.05.006