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Fuel Electricity and Plug-In Electric Vehicles in an LCFS: Appendices

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National Low Carbon Fuel Standard Study

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Discussion Draft

The document examines approaches for calculating fuel electricity carbon intensity and incentives fo increasing electricity fuel usage in a National Low Carbon Fuel Standard framework

About the National LCFS Study

The National LCFS Study has two objectives: 1) compare an LCFS with other policy instruments that have the potential to significantly reduce transportation GHG emissions from fuel use; and (2) propose a policy structure for an LCFS that would be most effective and implementable. The study is a collaboration between researchers from the following institutions: Institute of Transportation Studies, University of California, Davis; Department of Agricultural and Consumer Economics/Energy Biosciences Institute, University of Illinois, Urbana-Champaign; Margaret Chase Smith Policy Center, and School of Economics, University of Maine; Environmental Sciences Division, Oak Ridge National Laboratory; Green Design Institute of Carnegie Mellon University; and the International Food Policy Research Institute.

A series of white papers present analyses conducted over the past year regarding possible impacts of a national LCFS and design and implementation issues. These topics include:

- Economic Costs and Benefits of a National Low Carbon Fuel Standard and Implications for Greenhouse Gas Emissions
- Energy Security and a National LCFS
- Analysis of Indirect Land Use Change (iLUC) Impacts under a National LCFS iLUC Policy Options, and Policy Design Issues for a National LCFS
- Costs and Credit Trading of a National LCFS
- Handling Uncertainty in Life-Cycle Carbon Intensity in a National LCFS
- Policy Design Considerations for Electricity in a National LCFS

Our goal is to propose the design of a robust national LCFS policy that balances environmental, political, and economic goals and is readily implementable and enforceable in terms of data availability, simplicity, etc. The specific design recommendations will be summarized in a forthcoming Policy Design Report (PDR). The results of the above white papers will also be summarized in a forthcoming Technical Analysis Report (TAR).

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For project information, please contact Daniel Sperling (dsperling@ucdavis.edu) and Sonia Yeh (slyeh@ucdavis.edu), co-directors; or Jamie Rhodes (jsrhodes@mac.com), managing director. Additional information of the project can be found at http:// steps.ucdavis.edu/research/Thread_6/lcfs/national-lcfs

Appendix A – Energy Efficiency Ratio for PEVs

Recent test data from the EPA on current PEVs, the Nissan Leaf and the Chevy Volt, show equivalent fuel economy for these vehicles is quite high (EPA combined 99 and 93 mpgge[1], respectively) when using electricity (EPA 2011). Comparison of these fuel economies with equivalent ICE vehicles, Nissan's Versa (combined 27-30 mpg, depending on transmission type) and the Chevy Cruze (combined 27-28 mpg, depending on engine displacement), yield additional data points for the EER of driving on fuel electricity.

Table A1. Fuel economy data for PEVs and equivalent ICE vehicles (EPA 2011).

	Sticker Fuel Economy (mpgge)			**Sticker Fuel Economy (mpgge)**
Nissan Leaf	99 (0.34 kWh/mi)		Chevy Volt (CD)	93 (0.36 kWh/mi)
Nissan Versa	27 (auto), 30 (CVT)		Chevy Cruze	27 (1.8L), 28 (1.4L)
EER ratio	**3.7 (auto), 3.3 (CVT)**			**3.4 (1.8L), 3.3 (1.4L)**

These EER values are currently in the range of 3.3 to 3.7. However, current CAFE fuel economy standards will increase new car fuel economy for gasoline vehicles by approximately 40% (from 27.5 to 39 mpg) by 2016. Given the high efficiency of PEVs and the potential for increasing gasoline vehicle efficiency, it is likely that the value of EER will decrease somewhat over time. As additional PEVs are introduced into the market, this will provide a greater database for comparing fuel economy and calculating EER.

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[1] The fuel economy is given in mpgge (miles per gallon of gasoline equivalent) to enable energy use comparisons with gasoline powered vehicles.

Appendix B - PEV scenarios for LCFS compliance

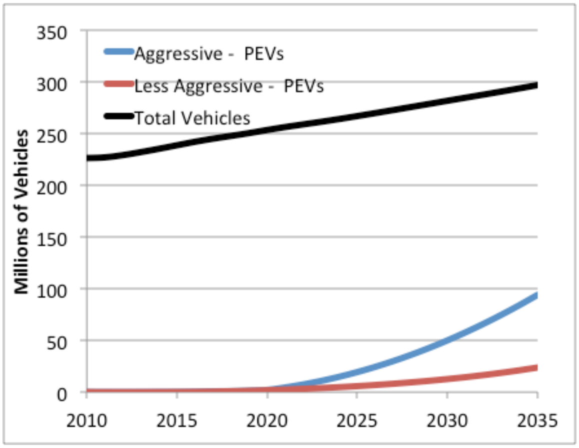
B1. PEV fleet share and miles powered by electricity

The impact of PEVs on the near- and medium-term implementation of the LCFS was estimated based upon scenarios developed in two studies, an analysis from the California Air Resources Board (ARB 2009) in support of their Zero Emission Vehicle (ZEV) rulemaking and the National Research Council's recent report on Plug-In Hybrid Electric Vehicles (NRC 2010).

Two scenarios are developed from these two studies. An *Aggressive* case is developed that is based upon ARB analysis, which assumes significant policy drivers for PEVs are put in place in California resulting in rapid deployment of PEVs. This scenario is extended to other parts of the US by assuming that California represents about 20% of the total US PEV market (it is about 12% of the US light-duty vehicle market). A *Less Aggressive* scenario is developed from a "probable" scenario developed in the NRC analysis.

The *Aggressive* scenario assumes that 1 million PEVs are cumulatively sold by 2017, 10 million by 2023, and 50 million by 2030. The *Less Aggressive* scenario still a relatively optimistic scenario, which has 1 million PEVs sold by 2019 and 12 million by 2030, which is consistent with market share growth that has been seen by gas electric hybrid vehicles. In both scenarios, total light duty cars and trucks grow from 227 million in 2010 to 282 in 2030 (see Figure B1).

This analysis made assumptions about the mix of types of electric vehicles that would be sold (i.e. PHEV10s, PHEV20s PHEV40s and full BEVs) for each scenario. In the *Aggressive* scenario, the mix of PEV types stabilize in the fleet at 15% PHEV10s, 55% PHEV40s and 30% BEVs by 2022 while in the *Less Aggressive* scenario, the mix of PEVs stabilizes at 60% PHEV10, 30% PHEV40 and 10% BEV. These scenarios are more optimistic than the AEO2010, achieving only about 3 million PEVs in 2030 (80% PHEV10s and 20% PHEV40s in the 2020-2035 timeframe).



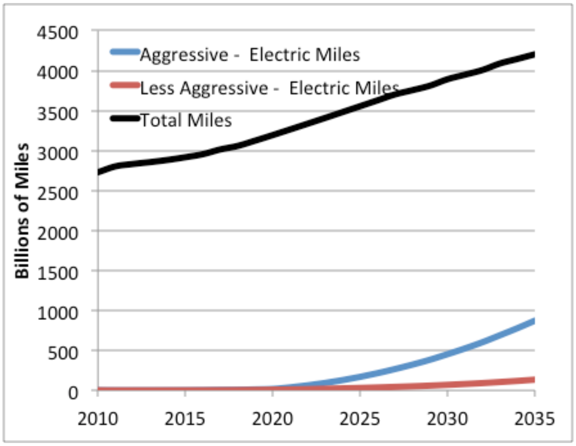


Figure B1. National fleet penetration of PEVs and miles powered by electricity for two scenarios.

Since PHEVs have limited battery capacity, only a portion of their driving will be powered by electricity. The mix of vehicles in the *Aggressive* scenario leads to 65% of PEV driving powered by electricity, while the smaller sized batteries of the vehicles in the *Less Aggressive* scenario leads to only 40% of PEV driving powered by electricity. Coupling PEV penetration with the fraction of PEV miles powered by electricity provides an estimate of the miles powered by electricity for the two scenarios (see Figure B1).

B2. Electricity Carbon Intensity and LCFS compliance

The electricity carbon intensity for the *Less Aggressive* scenario is taken as the average value of US electricity generation from the AEO 2010 from 2010 to 2035. For the *Aggressive* scenario, a weighted average of carbon intensity from the seven lowest CI electricity regions (representing 42% of total electricity generation) in the AEO2010 was used. The GREET model was used to estimate generic upstream emissions for different types of powerplants and these values were added to the direct emissions from the power plant.

Table B1. PEV contributions to LCFS compliance under two scenarios

	Aggressive scenario					*Less Aggressive* scenario				
	Carbon Intensity (g/MJ)	% PEVs in Fleet	% Elec Miles	LCFS CI	CI % Reduction	Carbon Intensity (g/MJ)	% PEVs in Fleet	% Elec Miles	LCFS CI	CI % Reduction
2010	48.6	0.0%	0.0%	93.0	0.0%	62.0	0.0%	0.0%	93.0	0.0%
2015	45.8	0.1%	0.1%	93.0	0.0%	61.0	0.1%	0.0%	93.0	0.0%
2020	45.1	0.8%	0.6%	92.7	0.3%	60.1	0.7%	0.3%	92.9	0.1%
2023	45.3	4.2%	2.7%	91.7	1.4%	60.0	1.5%	0.6%	92.8	0.2%
2025	46.0	7.3%	4.8%	90.8	2.4%	59.6	2.2%	0.9%	92.7	0.3%
2030	45.9	17.8%	11.6%	87.5	5.9%	58.9	4.5%	1.8%	92.4	0.7%
2035	45.9	31.7%	20.7%	83.2	10.5%	58.4	8.0%	3.2%	91.9	1.2%

[1] Assumes an Energy Efficiency Ratio (EER) of 3.0 for electricity

In 2023, PEVs could reduce the CI of the fleet by 1.4% or 0.2% for the *Aggressive* and *Less Aggressive* scenarios respectively. By 2030, the reduction could be as high as 5.9% and 0.7%. There is quite a large range in the potential contribution of PEVs and electricity to LCFS compliance (see Figure B2). However, even with quite optimistic assumptions about vehicle penetration, PEV mix, and electricity carbon intensity, most of the LCFS compliance will need to come from other sources in the near to medium-term. The impact of PEVs in the near term is constrained by their rate of growth. But after 2030, PEVs could potentially have a larger role in LCFS compliance because of acceleration in PEV fleet share.

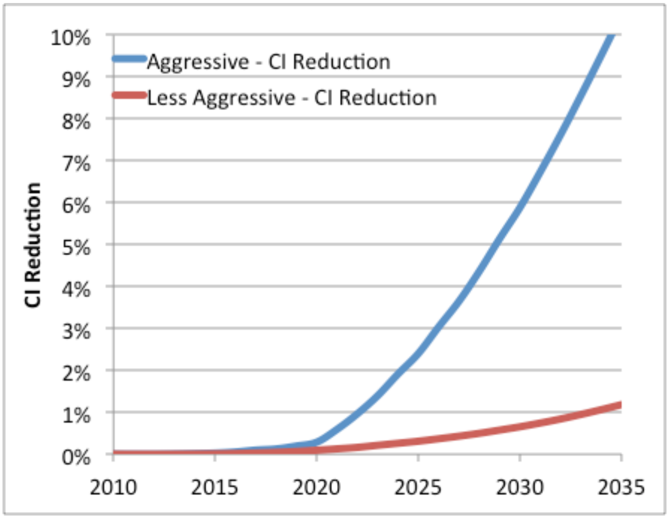


Figure B2. Contribution to fleet CI reduction from fuel electricity in two scenarios.

An important caveat to this assumption is that it assumes that PEVs are driven as much as a conventional vehicle and that they displace an average vehicle in the fleet (not a smaller compact vehicle) such that the average mpg of the remaining conventional vehicles does not change.

Appendix C. Description of LEDGE-CA model and scenario analyzed

C1. Model description

The Long-term Electricity Dispatch Model for Greenhouse gas Emissions in California (or LEDGE-CA) model is a simulation of the California electricity system that dispatches existing resources to meet electricity demands for the state. It is based upon previous work that describes a more detailed model for the current (2010) California grid called the EDGE-CA model (McCarthy et al 2009).

The overall goal of the model is to determine the hourly operation of the electricity system in order to meet electricity demands and then calculate generation mix and emissions from the system. Because of the detailed hourly (8760 hours/year) specification of the model, it can be used to determine generation mix and emissions for each hour of the year. The grid composition is an input assumption for the LEDGE-CA model, and the model will determine which resources in the existing capacity mix to dispatch in any given hour to meet the specified demands. As a result it does not optimize the composition of the power plants on the grid to minimize costs. Thus, changes in electricity demand patterns that come about from different PEV charging profiles do not affect the mix of power plants and simply change the operation of the existing capacity.

LEDGE-CA does not model system imports and treats the state as one electricity region.

C2. 2030 scenario assumptions

Table shows the composition of the California grid in 2030 and the order in which the resources are dispatched. Hydro is a special case because it is an energy-constrained, rather than capacity-constrained resource. Hydro is dispatched in order to minimize the cost of fossil dispatch. Wind and solar are intermittent resources that have a set hourly profile and are dispatched according to their hourly availability not their total capacity.

Table C1. Grid composition in 2030 for scenario analysed and the loading order

Power Plant Type	*Plant Capacity (MW)*
Nuclear	4390
Coal	0
Biomass	2615
Geothermal	4023
Wind	13828
Solar	8716
Hydro	7000
Natural gas combined cycle	27667
Natural gas combustion turbine	22333
Total	**90572**

Table provides a description of the different charging profiles. Two of the profiles (Offpeak and Workday) are passive, in that they are fixed demands that are imposed on the system. The other two profiles (Load-level and Min Cost) are active profiles in the sense that they can respond to system conditions (specifically other electricity demands as well as renewable supply).

Table C2. Description of different charging profiles analysed

Timing profile	***Description***
Offpeak	Fixed (passive) profile consisting of mostly off-peak charging (84%), with some charging during the day.
Workday	Fixed (passive) profile consisting of relatively even charging throughout the day, with dips during morning and evening commuting hours, when many vehicles are on the road and not plugged in.
Load-Level	An active demand profile with off-peak charging, using a valley-filling approach to flatten overall demand profile.
Min Cost	Active demand profile in which model distributes daily vehicle electricity demand to flatten fossil supply profile. Uses valley-filling approach on supply from thermal power plants.

Appendix D. Factors affecting regional PEV electricity demands

Regional electricity demand (both the timing and magnitude) in the absence of PEV demands is important to consider. Areas that use less electricity, such as those in mild climates may see a greater proportion of their demand come from PEVs. Alternatively, in areas with large per-capita electricity demand, additional PEV recharging demands will be relatively smaller for the same number of vehicles and thus, presumably place a lower strain on the regional grid system.

D1. Regional distribution of PEVs

Given that the first PHEVs and new generation of BEVs have only just been released, there is not any meaningful historical data of the spatial distribution of national PEV sales to use as the basis for projecting the regional distribution of future sales and thus fuel electricity demands. An IRC analysis has speculated that adoption of the Toyota Prius can be used as a proxy for the potential spatial distribution of PEV sales (IRC 2010). The largest concentration of Prius sales have occurred on the west coast and the Northeast states.

The deployment of hybrid electric vehicles such as the Toyota Prius in the past decade (1999 to 2009) has been mainly limited to the "early adopter" market. These consumers are generally interested in new technologies, possess environmental values, have high incomes and education levels and willing to pay a premium to adopt fuel efficient, and green technologies. This same set of attributes are expected of the early adopter crowd for PEVs. As a result, the spatial distribution of Prius adoption may be a useful starting point for the adoption of PEVs.

Some important caveats to the use of Prius data are that it is a single compact vehicle sold by a Japanese manufacturer, so regions with low Prius sales might still be willing buyers of PEVs in a range of vehicle types (including larger vehicles) and from domestic manufacturers. Given these considerations, data on hybrid vehicle sales generally including hybrid pickups and SUVs from a range of manufactures (both domestic and foreign) would also be useful.

D2. Other factors governing vehicle electricity demands

Beyond vehicle adoption, which would be the primary source of spatial variation for PEV demands, there are other factors that will also influence the amount of electricity used per PEV and thus regional electricity demands from PEVs. These factors are not explicitly quantified in this paper, but can have an important second-order effect on the level of impact that PEV demand will impose on the supply system.

One important factor governing the quantity of electricity demanded from a PEV is the regional differences in VMT per vehicle; drivers in the Northeast states and West Coast states tend to drive much less than the rest of the country (USDOT 2010).

Also important is the type of driving that is done. In large metropolitan areas, a greater proportion of miles driven are city miles, which involve more stop and go and for PEVs, this generally results in slightly greater energy usage per mile than highway miles.

Another important factor for energy use is the size and type of vehicle. Larger, heavier vehicles such as pickup trucks and SUVs will use more electricity than lighter, smaller cars to go the same distance, especially since batteries for these larger vehicles will be quite heavy. There are important regional differences in the mix of vehicles that are purchased and driven around the country.

Regional climate differences will also play an important role. Because of the efficiency of PEVs, the energy demands associated with space heating and cooling the passengers in a vehicle can be a significant proportion of total energy use and consequently regions with higher cooling and heating demands can expect to have greater electricity use per mile.

Finally, the deployment of infrastructure will also play a role in the amount of electricity that is used to recharge PEVs. The availability of charging infrastructure will alter patterns of charging (i.e. if a consumer has access to workplace charging, then potentially around half of their charging can occur during the daytime, as opposed to 100% nighttime charging if there is no access to workplace charging) (Axsen et al 2011). Also, to the extent that PEV owners fully utilize their battery capacity, having greater access to charging infrastructure, during the day and in public places, will increase the fraction of miles that are powered by electricity from the grid. Public charging infrastructure deployment is expected to be deployed more widely in larger metropolitan areas.

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