

# Strategic Use of Electric Vehicle Charging to Reduce Renewable Energy Curtailment on Oahu

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*An analysis of the use of electric vehicle charging to mitigate renewable energy curtailment based on detailed grid simulation models prepared by General Electric.*

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*Final Report*

*September 18, 2013*

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## I. Executive Summary

Wind and solar photovoltaic generation systems are supplying an increasing share of electrical power generation on Oahu. Unlike conventional power supplies that can be dispatched as needed to match demand and provide ancillary services for grid stability, these renewable production sources are intermittent by nature. This is generally not a operational challenge until the contributions from wind and solar become a significant portion of power generation on the grid. Across much of North America and Europe, large grid networks are interconnected, often across state and national boundaries. The increased buffering provided by this capacity enables significant amounts of intermittent renewable resources to be accepted in any specific region. With the relatively small, isolated electricity grid on Oahu, there are limited options to balance the intermittency. When wind speed drops or cloud cover reduces renewable generation, conventional thermal generation using petroleum is typically used to fill the gap. When the renewable energy supply exceeds that which can be accepted the excess energy is rejected or curtailed.

Electric vehicles (EVs) offer an opportunity to manage demand and potentially reduce the amount of curtailed energy by controlling when EVs are charged. This report explores the impact of various theoretical EV charging profiles and compares their potential to reduce the amount of curtailed energy. This analysis builds on the previous modeling conducted by the Energy Consulting Department of General Electric International, Inc. (GE). In this analysis, renewable energy penetration up to 1000 MW of combined wind and solar were considered. While controlled charging of the EVs is shown to reduce the curtailment, the day-to-day variability of the curtailment limits the amount of energy utilized when using only EV charging as a mitigation strategy. The overall savings in petroleum and emissions were also calculated and surpassed average fuel economy vehicles, but were comparable to efficient, gasoline-powered hybrid vehicles. This work can be used to inform planning, policy development and purchasing choices.

## II. Introduction

Grid-connected, electric-drive vehicles play a role in the holistic approach to meeting the Hawaii Clean Energy Initiative (HCEI) goals. Hawaii has been targeted by the major auto manufacturers as an ideal launch state for EVs as a result of limited driving distances, moderate climate and supportive policy initiatives. Given these favorable conditions, some

pundits have suggested that Hawaii may lead other states in adopting EVs. If so, this will add a potentially significant additional load onto Oahu's electricity grid.

Although seasonal demand for electricity in Hawaii is relatively steady, demand varies quite widely over a 24 hour period. During a typical week day, demand starts out low around midnight (~ 800 MW), increases by early morning and levels off or peaks around noon, then reaches a critical peak between 5 PM and 9 PM (~ 1,200 MW load), before falling off toward midnight<sup>1</sup>. EV charging may result in additional strain on the grid if EV drivers charge their vehicles during peak demand, such as upon arrival at home after work and school. Conversely, controlling the timing of electric vehicle charging can make better use of intermittent wind and solar resources.

Hawaii's energy infrastructure and electricity consumption are unique among the States. Electricity production is affected by the state's isolation and dependence on imported oil, with about 88% of its energy imported, and approximately 74% of electricity generated from oil. On the continental US, utilities have more choices in energy sources for electricity production, including cost-effective nuclear, coal, natural gas and large scale hydroelectricity. This leads to a relatively stable price of electricity along with more options for balancing intermittent renewable energy generation. By comparison, the electrical grid system on each Hawaiian island is independent, with no neighboring utilities from which to draw power in the event of a problem<sup>2</sup>. This requires additional backup capabilities built into each island system. Although gasoline prices at the pump in Hawaii are typically amongst the highest in the nation, electricity costs are three times higher than the US average<sup>3</sup>. Added to the cost challenge in Hawaii is the instability associated with petroleum. The US Energy Information Administration (EIA) projects oil to reach as high as \$200 per barrel by 2030 and up to about \$240 per barrel by 2040<sup>4</sup>. This illustrates the necessity of increasing the share of stable-priced energy solutions, such as wind and solar, together with exploring benefits offered by controlled EV charging.

### III. Methodology

This report builds on data from a previous modeling effort by the GE. Under this contract to the Hawaii Natural Energy Institute (HNEI), GE conducted detailed modeling of future Base Cases for Oahu's grid with high penetration of wind and solar resources, along with a

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<sup>1</sup> Hawaiian Electric Company, <http://www.heco.com/> (accessed Jun. 11, 2013.)

<sup>2</sup> Hawaiian Electric Company, <http://www.heco.com/> (accessed Jun. 11, 2013.)

<sup>3</sup> DBEDT Monthly Energy Trends, [hawaii.gov/dbedt/info/economic/data\\_reports/energy-trends](http://hawaii.gov/dbedt/info/economic/data_reports/energy-trends).

<sup>4</sup> US Energy Information Administration (EIA), "Annual Energy Outlook 2011 Reference Case", Dec. 2010.

range of electric vehicle charging profiles<sup>5</sup>. The Base Cases examined in this report are summarized in Table 1, below listed by ascending amounts of curtailed energy. To put this in perspective, Base Case 1 with 500 MW of wind power and 100 MW of solar PV would supply more than 25% of Oahu’s electrical energy.

**Table 1.** Renewable power generation Base Cases combining wind and solar energy inputs examined by GE under contract from HNEI. The four Base Cases consider various combinations of wind and photovoltaic power over a range of 600 to 1000 MW, listed below in the order of increasing amounts of curtailed energy.

Base Case	Total Wind (MW)	Total Solar (MW)	Total Wind + Solar (MW)
1 (500W/100S)	500	100	600
4 (500W/300S)	500	300	800
3 (500W/500S)	500	500	1000
2 (700W/300S)	700	300	1000

The intent is to determine the amount of curtailed energy in each Base Case, and then see how much of that wasted energy can be used by a large number of EVs charging in different time profiles. As background to this EV analysis, a brief summary of pertinent GE modeling results is given here as follows.

GE added a load to the grid to simulate a large number of EVs and then modeled the effect of different charging profiles. GE set the EV load equal to the amount of curtailed energy in each Base Case. However, capturing the curtailed energy is less than perfect since wind and solar are intermittent resources that vary over the course of the day. When wind speed drops or cloud cover reduces renewable generation, conventional thermal generation using petroleum is typically used to fill the gap.

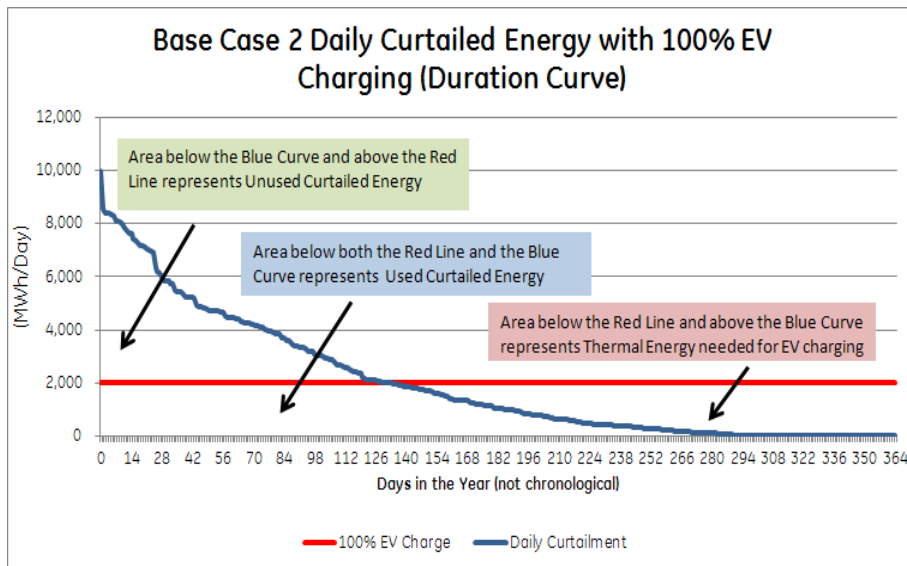
As described in the GE report, this variability of wind and solar power is critical in determining the amount of curtailed energy that can be used by the EV fleet. At best, the most sophisticated theoretical charging profile modeled by GE (Daily Perfect Tracking) captured 53% of the available curtailed energy (in the high wind, 1 GW renewable energy Base Case.)<sup>6</sup> The remainder of the power to charge the EV fleet (47%) comes from petroleum. This is clearly illustrated with a graph of the daily curtailed energy (Figure 1 below, from the GE report). Each day of the year has been organized from the day with the most amount of curtailed energy, to the day with the least amount of curtailed energy. The area below the blue curve represents the curtailed energy over a year. The area below the red line indicates the EV charging requirements and is about equally divided between curtailed energy to the left of the blue curve, and thermal generation from petroleum to the

<sup>5</sup> “Oahu Electric Vehicle Charging Study”, Prepared by GE Energy Consulting, for Hawaii Natural Energy Institute, June 10, 2013.

<sup>6</sup> Daily Perfect Tracking was the most complex charging profile modeled by GE Energy Consulting, “Oahu Electrical Vehicle Charging Study”, Rev. 5, June 10, 2013.

right of the blue curve<sup>7</sup>. Given the 1 GW Base Case with the most abundant curtailed energy and a very large fleet of EVs, this ‘best we can do’ theoretical charging profile captures only about half of the curtailed energy.

**Figure 1:** Daily curtailed energy with EV charging load represented by the red line (for GE Base Case 2 as an example, the high wind Base Case with 700 MW wind and 300 MW solar power and highest amount of curtailed energy, under daily perfect tracking EV charging).



This report focuses on four annual EV charging profiles created by GE, ranging from most simple called “Uniform Charging”<sup>8</sup>, to the “Annual Perfect Tracking”<sup>9</sup>, where EV charging tracks the annual curtailed energy pattern. Then looking at demand on the grid, GE considered practical profiles to implement in relation to the grid’s peak periods of electrical demand. The first of these, Profile 1, entails a charging pattern that ramps up at night and down during the day (Table 2). Profile 2 is similar but prevents EV charging during the grid’s critical peak demand period in the evening.

**Table 2.** Charging profiles summary.

Profile	EV Charging Description
Uniform Charging	constant
Perfect Tracking	perfectly tracks wind and solar energy
Profile 1	30% day time 70% evening & night time
Profile 2	30% day time 0% peak 70% night time

<sup>7</sup> Figure 14 extracted from the GE report, “Oahu Electrical Vehicle Charging Study”, Rev. 5, June 10, 2013.

<sup>8</sup> GE derived the uniform charging from an hourly average of the total amount of curtailed renewable energy over the year, for each renewable energy Base Case.

<sup>9</sup> This paper focuses on the Annual Perfect Charging profile, where GE based the profile on hourly averages of curtailed energy over a year, for each renewable energy Base Case (as opposed to the Daily Perfect Tracking Profile).



In this report, HNEI was able to build upon GE's results to further explore:

1. Curtailed energy used by EVs in each of the sixteen scenarios (four Base Cases and four charging profiles)
2. Additional fuel consumption for thermal generation attributed to the additional EV loads, and
3. Changes in CO<sub>2</sub> emissions resulting from the EV loads

The HNEI analysis began by comparing results from GE's complex computer models with results obtained using a relatively simple spreadsheet. HNEI examined the charging profiles under each energy Base Case to determine how much of the EV load could be powered by curtailed energy. The remainder of the EV load must be met by additional thermal generation from Hawaiian Electric Company's (HECO's) conventional power plants using petroleum. (The additional power is assumed to be non-baseload generation – cycling or peaking power plants that are brought online as necessary to meet demand, rather than baseload plants that run all the time.) This petroleum consumption provides power to the EVs plugged into the grid to supplement the variable power supply from curtailed wind and solar resources. Fuel consumption data was provided by the GE models, along with carbon dioxide (CO<sub>2</sub>) emissions.

This HNEI analysis focusses on fully-battery powered EVs although results are applicable to Plug-in Hybrid Vehicles (PHEVs). PHEVs run on a combination of electricity and gasoline, with the ratio dependent on driving patterns. Additionally, EVs have a larger battery capacity than PHEVs and rely entirely on electricity as a fuel source. (See Section D, "Fleet Size" for more on scaling results for PHEVs.)

Based on the average distance traveled per year (at 11,000 miles)<sup>10</sup>, the fuel economy (mileage) of the EVs was calculated by HNEI, along with CO<sub>2</sub> emissions per mile. Mileage and emissions were then compared to average gasoline vehicles (achieving 21.4 miles per gallon (MPG)<sup>11</sup>). The overall amount of petroleum used by the EVs was compared to the amount of gasoline used by the same number of average gasoline vehicles, to arrive at a net petroleum savings by EV's. Comparisons were also made to conventional highly efficient gasoline-powered hybrid vehicles (run entirely on gasoline, as opposed to PHEVs). These calculations estimate the overall annual system savings for petroleum and CO<sub>2</sub> achieved by converting gasoline vehicles on Oahu to grid-connected EVs, under sixteen future scenarios with high penetrations of wind and solar energy.

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<sup>10</sup> Annual miles traveled is based on Market Trends Pacific report for HNEI rounded up to 11,000 and US DOT 2011 annual mileage rounded down to 11,000.

<sup>11</sup> US Department of Transportation, Office of Highway Policy Information, average of 21.4 MPG for all light duty vehicles, 2011.

## IV. Results

### A. HNEI Spreadsheet Modeling

With hourly EV load and curtailed energy data from the GE models as input, the reduction in curtailed energy for each EV charging profile was calculated using a simple spreadsheet. Spreadsheet results were within ½ of one percent (0.22% to 0.45%) of the GE modeling results. Consequently, the spreadsheet calculations for reduction in curtailed energy were deemed sufficiently accurate for the additional analyses performed under this study.

This is important as this simple spreadsheet can be used when actual hourly data becomes available for curtailed energy and EV load. For example, wind energy on Maui is curtailed when demand is exceeded, so various EV charging profiles could be analyzed using these spreadsheets.

### B. Curtailed Energy

With increasing input of wind and solar power to the electrical grid, there is a corresponding increase in the amount of wasted or curtailed energy (Table 3.) The amount of energy that must be curtailed tends to be higher with increasing proportions of wind resources (compare Base Cases 3 and 2). Wind’s higher variability becomes apparent by comparing the curtailment results of the higher wind in Scenario 4 and the even mix of wind and solar in Scenario 3. (For example, when wind power is generated at night, much of it may be curtailed, compared to solar power generated during the day when the demand for electricity on Oahu is much greater.)

**Table 3.** Curtailed energy in each Base Case. (Base Cases are numbered according to the GE study, listed below with the amount of wind (W) and solar (S) photovoltaic power).

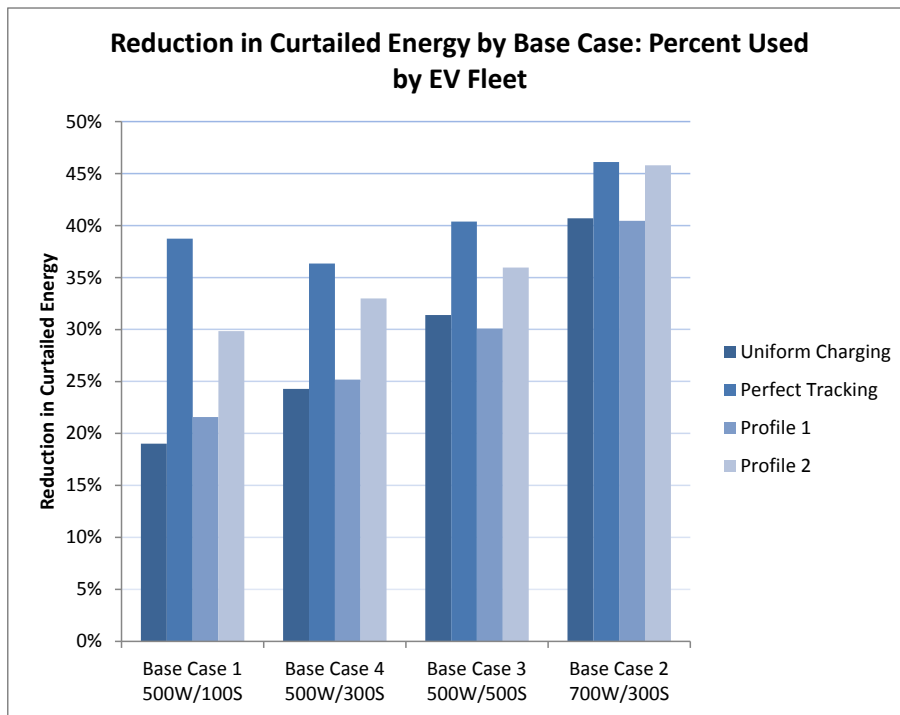
Base Case	Total Wind + Solar (MW)	Curtailed Energy Available (GWh)
1 (500W/100S)	600	210
4 (500W/300S)	800	262
3 (500W/500S)	1000	401
2 (700W/300S)	1000	736

### C. EV Charging Profiles and Reduction of Curtailed Energy

As expected, with more abundant curtailed energy, EV charging becomes more effective in reducing that wasted energy. Figure 2 (below) shows how the EVs reduce curtailed energy in each Base Case (as a percentage reduction) compared with the total amount of curtailed

energy before any EVs were connected to the grid. Not surprisingly, results for Perfect Tracking<sup>12</sup> are most successful in making use of curtailed renewable energy in all Base Cases. The least successful profiles are uniform charging along with Profile 1 (with 30% day time charging and 70% night time charging). Profile 2 (with 0% critical peak period) captures from 30% up to 46% of the curtailed energy from future Base Cases ranging from the least to the most curtailed energy (600 MW up to 1 GW of wind and solar power). This is assuming all EVs are charged following the charging profile. Profile 2 is almost the same as Perfect Tracking under the high wind 1 GW Base Case, achieving approximately 46% reduction in curtailed energy. This indicates that an effective charging profile could be reasonably straight forward to implement using incentive programs such as HECO’s pilot Time of Use electricity rates. Therefore this practical charging profile (Profile 2) is the focus of this report going forward.

**Figure 2.** Reduction in curtailed energy used by the EVs under different charging profiles, expressed as a percentage of total curtailed renewable energy for each base case.



#### D. Fleet Size

In order to create the models, GE assumed that the total EV load is exactly equal to the curtailed energy for each Base Case. From the curtailed load the equivalent number of EVs (fleet size) for each Base Case is derived for use in this analysis. HNEI calculated the

<sup>12</sup> GE’s Annual Perfect Tracking profile.

number of fully battery-powered vehicles to obtain the fleet size in each Base Case<sup>13</sup>. The number of EVs can be scaled up to attain the corresponding number of PHEVs that use gasoline as well as electricity.<sup>14</sup> Of course this number is a product of the modeling assumptions, rather than a true indication of the likely number of EVs in Oahu’s future. (More on projected levels of EVs is presented below in Section I “Projections for EV Fleet Size”.) The numbers of EVs from the modeling results are shown in Table 4 (below).

**Table 4.** EV fleet size (total number of EVs) in each Base Case.

Base Case	Total Wind + Solar (MW)	Number of EVs (equiv. to curtailed load)
1 (500W/100S)	600	56,094
4 (500W/300S)	800	69,926
3 (500W/500S)	1000	107,127
2 (700W/300S)	1000	196,701

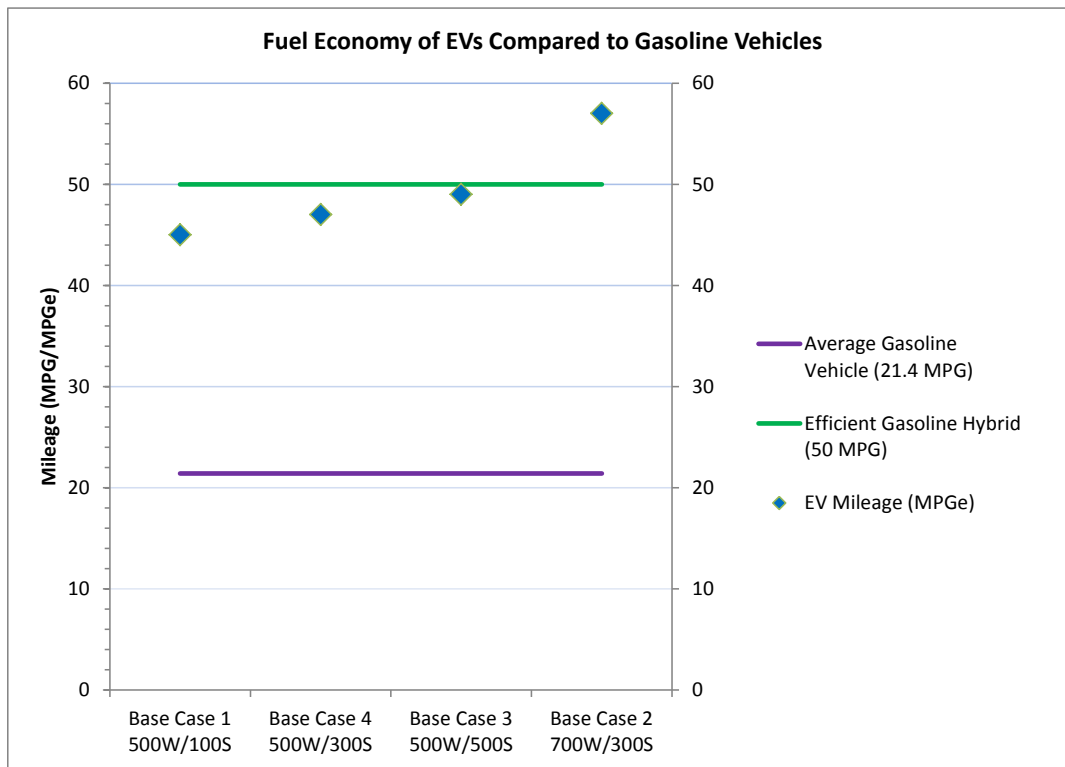
### E. Mileage

To compare the fuel economy of EVs to gasoline vehicles, calculations were performed to estimate how far an EV can travel on the equivalent of one gallon of gasoline, with results expressed in terms of mileage. EV mileage was determined from the additional petroleum consumed through thermal generation of electricity to power the fleet of EVs divided by the total number of EV miles driven in each renewable energy Base Case (Figure 3 below). Results ranged from approximately 45 to 57 miles per gallon equivalent (MPGe units, equivalent to MPG of gasoline for conventional gasoline vehicles). Compared to an average fuel economy vehicle (getting 21.4 MPG), this EV mileage clearly shows the advantages of powering EVs from a future Oahu grid with surplus renewable energy. However, it takes the high wind Base Case 2 for EV mileage to exceed that of a 50 MPG gasoline-powered hybrid vehicle.

<sup>13</sup> Based on US DOE’s data for a representative EV with 34 kW-hrs/100 mi, <http://www.fueleconomy.gov/>.

<sup>14</sup> A factor of 2.7 can be used to multiply the number of EVs to determine a corresponding number of PHEVs, based on US DOE’s PHEV data for a representative EV with 24 kWh of battery capacity, and a representative PHEV with 4.4 kWh battery capacity with average distance traveled on the battery versus gasoline, <http://www.fueleconomy.gov/>.

**Figure 3.** EV fuel economy in each renewable energy Base Case (and charging Profile 2) in order of ascending amounts of curtailed energy, compared with average gasoline vehicles and efficient gasoline-powered hybrid vehicles (in miles per gallon equivalent (MPGe) to gasoline, and MPG).



The disparity between these results and the US Environmental Protection Agency (EPA) fuel economy ratings for EVs arises from the fact that EPA ratings do not include electricity production. A more complete “(oil) well to wheels” standard was developed by the US Department of Energy (US DOE) more than a decade ago<sup>15</sup>. Published as part of a rule-making process, this standard creates comparable mileage figures for both gasoline-powered vehicles and electrically-powered vehicles on an energy equivalent basis. According to this standard, at the average US power plant only 32.8% of the potential energy in the fossil fuel is converted to electrical energy. The DOE further reduced the efficiency to 30.3% to account for transmission losses. For gasoline powered vehicles, the DOE also created a factor to account for the efficiency of refining and distributing gasoline, resulting in a 20% increase in the amount of gasoline consumed. But rather than adjusting established MPG standards for gasoline vehicles, the DOE used this factor to improve the electric vehicle MPGe. So the 30.3% electricity efficiency factor for electric drive vehicles was increased to a final adjustment factor of 36.5%. Using this US DOE adjustment factor

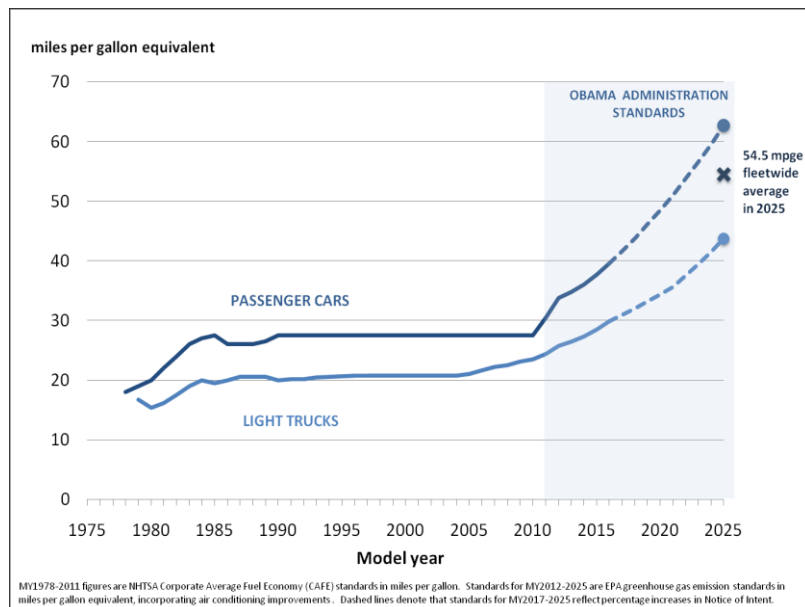
<sup>15</sup> US Department of Energy, Office of Energy Efficiency and Renewable Energy, 10 CFR Part 474, “Electric and Hybrid Vehicle Research, Development, and Demonstration Program; Petroleum-Equivalent Fuel Economy Calculation”, Federal Register, Volume 65, No. 113, Rules and Regulations, June 12, 2000.

gives a well to wheels mileage of 36 MPGe for an EV powered on the average US electrical grid, (as compared with 99 MPGe by EPA standards).

To put this into perspective for Oahu’s existing grid, (before the high penetration of wind and solar energy is added to the grid in these future Base Cases), EVs on Oahu’s current electrical grid achieve approximately 32 MPGe<sup>16</sup>, based on a DOE “well to wheels” mileage calculation.

Conventional gasoline-powered hybrid vehicles are expected to contribute significantly to the national Corporate Average Fuel Economy (CAFÉ) standards targeted to reach 54.5 MPG fleet average for new vehicles by 2025 (Figure 4)<sup>17</sup>. These standards are a weighted average for manufacturers’ fleets of new model cars and light trucks. CAFÉ standards use the EPA standard for EVs (not the US DOE’s “well to wheels” guideline).

**Figure 4.** Corporate Average Fuel Economy (CAFÉ) standards



## F. Total Petroleum Fuel Consumption

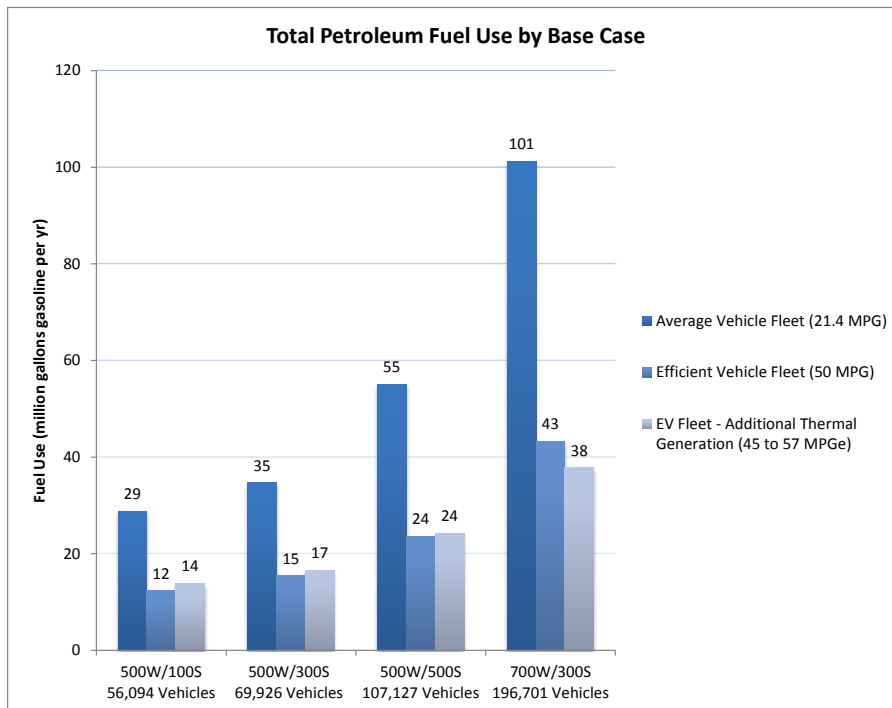
The amount of fuel consumed each year by the EV fleet in this analysis is compared to the amount consumed by the same number of gasoline vehicles. As stated earlier, petroleum consumed by the EV fleet in each scenario comes from the additional thermal generation

<sup>16</sup> Based on Oahu power plant heat rate data published in the Oahu Wind Integration Study (OWIS) and the US DOE “well to wheels” mileage calculation factors of; 0.924 for average electricity transmission efficiency, 0.830 for petroleum refining and distribution efficiency, and multiplying by an additional 20% to account for the efficiency of refining and gasoline distribution.

<sup>17</sup> White House Fuel Economy Report, “Driving Efficiency: Cutting Costs for Families at the Pump and Slashing Dependence on Oil”, 2011.

needed to balance the variable power captured from excess wind and solar energy<sup>18</sup>. Figure 5 (below) shows the amount of petroleum used each year by the same number of average US fuel economy vehicles<sup>19</sup> (dark blue), efficient hybrid vehicles (medium blue) and by EVs (light blue)<sup>20</sup> for each Base Case and associated fleet size. Replacing the same number of average gasoline vehicles with hybrids and EVs results in significant petroleum savings.

**Figure 5.** Yearly total petroleum consumption comparison for average gasoline vehicles, gasoline-powered hybrids, and EVs for each Base Case and associated fleet size. Fuel use is in millions of gallons of gasoline (equivalent units) per year.



### G. Displaced Petroleum

Clearly EVs on Oahu’s grid now and in the future save fuel compared to average gasoline vehicles. Both EVs and highly efficient gasoline-powered hybrid vehicles offer significant (~50%) reductions in overall petroleum-based fuel consumption compared with average gasoline vehicles (Figure 4 above).

<sup>18</sup> GE models provided the fuel consumption figures for each scenario, and HNEI calculations were made to convert gasoline to an energy equivalent amount of diesel/distillate fuel oil used by the power plants, based on US DOE data for energy content.

<sup>19</sup> US DOT, FHWA, 2011 average fuel economy all light duty vehicles, and US DOE energy content conversion factors for diesel/distillate equivalent units.

<sup>20</sup> Based on the 2011 Toyota Prius as a representative PHEV with a combined mileage of 50 MPG, and a 2011 Nissan Leaf as a representative EV, <http://www.fueleconomy.gov/>.

Petroleum savings for each Base Case’s EV fleet in this analysis, compared with the same number of average gasoline vehicles, are listed in Table 5 (below). Savings range from 15 million to 63 million gallons of gasoline per year, (or 319,000 up to 1.35 million barrels of diesel or distillate fuel oil per year)<sup>21</sup>. This equates to 268 up to 322 gallons of gasoline saved per year, for each average gasoline vehicle replaced by an EV under the future scenarios.

Compared to the same number of average gasoline vehicles, a fleet of highly efficient gasoline-powered hybrid vehicles save somewhat more petroleum than the same number of EVs in these future Base Cases, except for the high wind Base Case with 700 MW of wind and 300 MW of solar power (Table 5). Fuel savings for the EV fleets (compared to average gasoline vehicles) ranged from 15 million to 63 million gallons of gasoline per year. Fuel savings for the gasoline-powered hybrids (compared to average gasoline vehicles) ranged from 16 million to 58 million gallons of gasoline per year, (or 350,000 to 1.2 million barrels of diesel or distillate fuel oil per year).

**Table 5.** Displaced petroleum by Base Case for a gasoline-powered hybrid fleet and an EV fleet versus the same number of average mileage gasoline vehicles (in million gallons of gasoline (equivalent units) per year).

Base Case

	500W/100S 56,094 Vehicles	500W/300S 69,926 Vehicles	500W/500S 107,127 Vehicles	700W/300S 196,701 Vehicles
Petroleum Displaced by <b>Hybrid Fleet</b> vs Average Fleet (m gal gasoline/yr)	16	19	31	58
Petroleum Displaced by <b>EV Fleet</b> vs Average Fleet (m gal gasoline/yr)	15	18	31	63

In this analysis, petroleum savings from conventional hybrids are not substantially different from that achieved by EVs. Although this report is focused on future levels of wind and solar energy on the grid, other renewable sources of power generation along with power system technologies and operating strategies offer some additional potential to reduce EV-associated petroleum usage. For example, recent efficiencies for new power plants have increased to as high as 60%<sup>22</sup> (in contrast to the average US power plant efficiency of 32.8% in the year in 2000<sup>23</sup>).

<sup>21</sup> Displaced petroleum derived from GE models and US DOE energy content (Btu) conversion factors used to obtain gallons of gasoline.

<sup>22</sup> Siemens; Energy Sector, Fossil Power Generation Division, <http://www.siemens.com> accessed Jun. 26, 2013.

<sup>23</sup> US Department of Energy, Office of Energy Efficiency and Renewable Energy.



Considering Oahu's entire passenger vehicle fleet, this represents an improvement of approximately 1 to 4 MPG (raising the average 21 MPG up to 22 to 25 MPG) to achieve the same 15 to 63 million gallons of gasoline savings per year achieved by a very large fleet of EVs (on a future grid with 600 MW up to 1 GW of wind and solar power, under charging Profile 2)<sup>24</sup>. Considering Oahu's current consumption of 500 million gallons of fuel per year for ground transportation as a whole<sup>25</sup>, this represents a fuel savings of 3% to 13%.

In the future, the Oahu grid may have more fuel from renewable sources such as ocean energy or biofuels, which would further reduce the amount of petroleum consumed by EVs. According to the US Energy Information Administration, "Hawaii has the world's largest commercial electricity generator fueled exclusively with biofuels; the State's energy plan aims for an agricultural biofuels industry that, by 2025, can provide 350 million gallons (8.3 million barrels) of biofuels". To put this into context, approximately 500 million gallons (12 million barrels) of fuel are used each year for electricity production state wide, and approximately the same amount is used for ground transportation.

## H. Emissions

Vehicle emissions are dependent on the fuel used as well as the fuel economy. As expected, CO<sub>2</sub> emissions determined in this study for EVs improve as more curtailed energy is consumed. Emissions range from 190 down to 146 grams of CO<sub>2</sub> per mile under the Base Cases in this study<sup>26</sup>. This contrasts with average gasoline vehicles at approximately 498 grams of CO<sub>2</sub> per mile and an efficient gasoline-powered hybrid at 213 grams of CO<sub>2</sub> per mile<sup>27</sup>.

According to the EPA, the personal vehicle market in the US is diversifying, with a much broader choice when it comes to fuel economy, CO<sub>2</sub> emissions, and power train technology. The number of SUV, pickup, and van models that have combined EPA labels of 20 mpg or more have increased by 71% in the last 5 years (2007-2012). There are six times more cars models with ratings of 30 mpg or more, and more than seven times as many car models with 40 mpg or more since 2007. Additionally, there are many more advanced technology vehicle choices than five years ago, with about twice as many conventional hybrid and diesel models on the market, as well as growing numbers of EV, PHEV, natural

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<sup>24</sup> 638,145 total passenger vehicles in Dec. 2012, DBEDT Monthly Energy Data.

<sup>25</sup> Fuel for ground transportation in 2010, DBEDT Hawaii State Energy Office, "Hawaii Energy Facts & Figures", January 2013.

<sup>26</sup> Calculated using thermal energy CO<sub>2</sub> emissions from GE models for the thermal generation, charging Profile 2, and EPA zero tailpipe emissions for the vehicles.

<sup>27</sup> US Department of Energy (US DOE) heat content of 124,000 Btu /gallon of gasoline, and 139,000 Btu /gallon of diesel/distillate (fuel oil) , and US Environmental Protection Agency (EPA) Office of Transportation and Air Quality, EPA-420-F-11-041, Dec. 2011, "Greenhouse Gas Emissions from a Typical Passenger Vehicle", 8,887 grams of CO<sub>2</sub> emitted per gallon of gasoline.

gas and fuel cell vehicles (although some have limited market availability at this stage.) Looking forward to the future vehicle mix in the context of EPA emission targets, only hybrids, PHEVs, natural gas vehicles and EVs can meet the EPA's 2025 CO<sub>2</sub> emission targets (which do not include DOE's "well to wheels" energy consumption or any life-cycle analysis, but are based on current power train designs and assuming air conditioning improvements)<sup>28</sup>.

## I. Projections for EV Fleet Size

If the projected numbers of EVs for the future are accurate, the total number of EVs will be much smaller than that used in the GE Base Cases. The HCEI Transportation working group's least optimistic projection was for 3,060 EVs and PHEVs on the road on Oahu by 2015, and 30,600 by 2030<sup>29</sup>. (HCEI's most optimistic projection was for 130,320 EVs and PHEVs by 2030.) HCEI projections were based on technology development forecasts from the National Academy of Sciences<sup>30</sup> (NAS) and Deutsche Bank<sup>31</sup>. The least optimistic Base Case is consistent with the goal set by the Obama administration and the US DOE's estimate of 1 million EVs nationally by 2015, equating to 2,900 EVs on Oahu<sup>32</sup>. Other forecasts include the following:

- Deloitte surveyed US electrical utilities, most of which expect EV penetration rates up to 1% of the entire US passenger fleet by 2015, and up to 5% by 2020<sup>33</sup>. (This equates to over 30,000 EVs on Oahu by 2020.)
- Pike Research has Hawaii leading all other states by 2020 with 12.3 % of sales as plug in vehicles, and US annual sales of at 400,073 by 2020<sup>34</sup>.
- Center for Climate and Energy Solutions (C2ES), estimates the production of 1,232,200 EVs and PHEVs nationally by 2015<sup>35</sup>, (corresponding to approximately 3,600 EVs and PHEVs on Oahu).

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<sup>28</sup> "Light Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2012", Office of Transportation and Air Quality, US Environmental Protection Agency, EPA-420-R-13-001, March 2013.

<sup>29</sup> Booz Allen Hamilton, "Hawaii Clean Energy Initiative Base Case Analysis: Quantitative Estimates Used to Facilitate Working Group Discussions (2008-2010)", R. Braccio, P. Finch, and R. Frazier, Booz Allen Hamilton, NREL Subcontract Report, March 2012. Projections for the State of Hawaii were reduced by the ratio of the number of passenger vehicles on Oahu, based data from State of Hawaii, Department of Business, Economic Development and Tourism (DBEDT), Monthly Energy Data for 2011.

<sup>30</sup> National Research Council, National Academy of Sciences, "Transitions to Alternative Transportation Technologies – Plug-In Hybrid Electric Vehicles", 2010, has EVs and PHEVs rising to 3 percent of new light-duty vehicles entering the US vehicle fleet by 2020, and 13 million by 2030.

<sup>31</sup> Deutsche Bank Securities, Inc., "Vehicle Electrification: More Rapid Growth; Steeper Price Declines for Batteries", 2010.

<sup>32</sup> US Department of Transportation, FHWA, Office of Hwy Policy Information, (US DOT), 2011 number of all light duty vehicles in Hawaii, and the percentage of passenger vehicles on Oahu from DBEDT Monthly Energy Data, 2011.

<sup>33</sup> Deloitte Center for Energy Solutions, "Charging Ahead: The Last Mile", 2012.

<sup>34</sup> Pike Research, "Electric Vehicle Geographic Forecasts", Dave Hurst, John Gartner, 3Q 2012.

<sup>35</sup> Center for Climate and Energy Solutions (C2ES), "Plug-In Electric Vehicles Market: State of Play", July 2011.

- JD Powers and Associates projects growth more conservatively for fully battery-powered EVs at 0.6% of US sales (107,998 vehicles), and 1.85% of global vehicle sales in 2020<sup>36</sup>. Sales of hybrids and PHEVs are predicted to grow steadily to 9.6% in 2020 (1,672,739 units).

With a much smaller EV fleet on Oahu, the curtailed energy in these future scenarios would become relatively more abundant and can be expected to increase the percentage captured. (Moving the red line down on the Daily Curtailed Energy graph in Fig. 1.) However decreasing fleet size also decreases the effect on overall fuel savings.

## J. EV Fuel Costs - 2011

This report presents a limited look at costs associated with EVs in comparison to average gasoline vehicles and gasoline-powered hybrids.

Simple fuel cost calculations were performed to compare the cost of fueling EVs with electricity and hybrids with gasoline. Costs were based on HECO's pilot "Time of Use" (TOU) rates for average residential electricity costs along with average gasoline prices on Oahu for 2011<sup>37</sup>. The fuel cost per mile was \$0.09 for the EV and \$0.08 for the highly efficient 50 MPG gasoline hybrid vehicle. For a break-even fuel cost on Oahu between the EV and highly efficient hybrid, the electricity rate would need to be \$0.23/kWh (versus the 2011 rate of \$0.32/kWh), or the EV would need to achieve an efficiency of 25 kWh/100 miles (compared with the current 34 kWh/100 miles used in this analysis). By way of comparison, the average gasoline vehicle fuel costs were \$0.19 per mile on Oahu (in 2011, for an average gasoline vehicle getting 21.4 MPG).

## V. Conclusions

Controlled, practical EV charging can make better use of surplus renewable energy from abundant wind and solar PV. However no matter how many EVs are on the grid on Oahu,

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<sup>36</sup> JD Powers and Associates, "Drive Green 2020", 2010.

<sup>37</sup> Calculations based on: US Department of Energy, Energy Efficiency and Renewable Energy's [www.fueleconomy.gov](http://www.fueleconomy.gov) using the 2011 Nissan Leaf, the Toyota Prius, and the Toyota Prius Plug-in as representative EV, highly efficient hybrid vehicle, and PHEV respectively; US DOT, 2011 mileage for "all light duty" vehicles and average mileage; State of Hawaii, DBEDT, Monthly Energy Data (for Oahu, 2011) average residential electricity and regular gasoline prices; US Energy Information Administration (EIA), 2011, average US gasoline and electricity prices, 2011. 2011 annual miles traveled is based on Market Trends Pacific report for HNEI rounded up to 11,000 and US DOT annual mileage rounded down to 11,000.

curtailed energy will never be perfectly matched with EV charging.<sup>38</sup> At best, roughly half of the curtailed energy can be captured. Electricity from the future Oahu grid to power an additional load from an EV fleet will be composed of both renewable energy and thermal generation under the conditions analyzed in this report. Wind power results in more curtailed energy than solar, due to the higher variability of wind as a renewable resource. In this analysis, additional thermal generation is produced from petroleum rather than future possibilities with renewable fuel sources. EVs as well as PHEVs and conventional gasoline-powered hybrid vehicles offer a significant savings over average gasoline vehicles, as does increasing the overall vehicle fleet mileage. However even with very high levels of curtailed energy from 600 MW to 1 GW of wind and solar on Oahu's grid and a very large fleet, EVs have a similar effect on reducing petroleum imports as the same number of highly efficient gasoline-powered hybrids, or increasing Oahu's overall passenger vehicle fleet mileage by approximately 1 to 4 MPG.

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<sup>38</sup> The GE modeling assumption that EV load is equal to the curtailed energy in each Base Case gives us a very large number of EVs on the grid, ranging from over 56,000 for the Base Case with the least curtailed energy, up to almost 200,000 EVs in the Base Case with the greatest amount of curtailed energy. This is assuming the EV fleet is composed of fully battery-powered vehicles with an average of 34 kWh/100 miles, along with an average of 11,000 vehicle miles traveled per year based on the Market Trends Pacific report.