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Los Angeles Air Force Base Vehicle to Grid Pilot Project

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Abstract

Compared to conventional vehicles, plug-in electrical vehicle (PEVs) have attractive operating characteristics; however, PEVs currently have a higher first cost, and this together with costly battery replacement make their life-cycle cost uncompetitive. One potential way to tip the owner cost balance towards PEVs is participation in grid ancillary services (AS) markets, one of multiple practices known as vehicle-to-grid (V2G). One V2G technology development effort is described here, and an update on its application to a mixed duty 40-vehicle 100% PEV pilot fleet demonstration at the Los Angeles Air Force Base (L.A. AFB or *the base*) is given. About half of these vehicles will participate in V2G markets. The project will assess both the technical challenge of V2G participation and the potential financial benefit. Optimization capability will ensure that the complex task of scheduling charging-discharging of vehicles achieves unimpeded fleet operations, energy cost minimization, and AS revenue maximization. All objectives must be jointly considered, the best overall bids submitted, and optimal scheduling implemented. V2G capable vehicles will participate in the fast response California Independent System Operator (CAISO) Regulation Up and Regulation Down (Reg.U+D) markets. Receipt and response within 4 seconds to dispatch instructions will be enabled by a remote Akuacom Inc. operated Demand Response Automated Server (DRAS), which receives secure CAISO instructions and forwards them using the Open Automated Demand Response (OpenADR) protocol. PEV fleet operation uses Bosch Software Innovations' eMobility Solution fleet management software suite, which provides the necessary additional front-end PEV fleet management tools and actually implements PEV charging-discharging. Optimization capability based on the Lawrence Berkeley National Laboratory's (Berkeley Lab's) Distributed Energy Resources Customer Adoption Model (DER-CAM) finds optimal scheduling for the fleet. Together these three technologies will form the PEV Fleet Optimization Model (PEV-fleetOPT). Early experience suggests that technically such a V2G scheme is feasible; however, any such project also must confront many policy hurdles. Olivine provides regulatory and interconnection guidance to the project, and the high regulatory barriers and complex interconnection requirements encountered represent an ongoing burden. Tackling these problems and capturing sufficient revenues from the market to move the economics of PEV operation poses a tough challenge.

Introduction

California is a leader in the worldwide effort to accelerate the transition of transportation systems towards a more sustainable environmentally benign basis (Ogden and Anderson 2011). Because the state has a relatively low carbon intensity economy overall, transportation contributes over 40% of all state greenhouse gas emissions. Vehicles using internal combustion engines (ICEs) are an undesirable, deeply entrenched, and strongly dominant technology, the pluses and minuses of which are all too familiar. In short, the high power density of ICEs combined with the exceptional convenience of liquid fossil fuels deliver low cost vehicles with great flexibility and a universal service infrastructure.

ICEs cause serious urban air pollution and noise, and they increase dependency on remote depletable sources of energy often controlled by unfriendly powers. Electrifying vehicle fleets can mitigate many of these negatives, but with a significant loss of convenience, increased operational complexity, and likely higher costs. PEVs have some technical limitations, such as limited and variable range depending on battery capacity, ambient temperature, driving style, use of cabin conditioning, etc.; however, much of PEVs' inconvenience derives from the absence of an established infrastructure, charging stations, fast charging standards, etc., as well as an incentive-based regulatory framework, e.g. lacking off-peak electricity rates impeding ready capture of vehicle to building (V2B) and V2G benefits. From a climate perspective, PEVs seem a mixed bag, emitting little to no CO_2 in normal operation, and yet potentially using electricity whose generation potentially does major climate damage. Converting primary fuels to electricity incurs large energy losses, but because PEV operating efficiency is very high, lower net transportation emissions result, compared to conventional fleets. Highly efficient hybrids do come close though. A Carnegie Mellon study suggests that PEV CO_2 emissions must be at least a quarter lower than from conventional fleets (Sovacool & Hirsh, 2009), and other studies have confirmed intuition that emissions of smog precursors, notably hydrocarbons and NOx, are dramatically lower. In fact, they are actually almost eliminated (ibid), and those tend to be emitted in less sensitive places and ways, i.e. from stacks remote from population centers. In locations such as California, where marginal power generation almost always comes from natural gas, the benefit is clearer. Further, over time the carbon content of marginal generation is likely to fall, so PEVs will have a stronger edge over conventional fleets. California has recently achieved its 2010 renewable portfolio standard of 20% eligible (excludes large-scale hydro) generation penetration (California Public Utilities Commission 2012). PEV performance relative to biofuel-powered vehicles is less clear, depending on the methods used to produce and distribute the fuels. Given these benefits, the State has actively promoted alternative fuel vehicles for some time, and the Governor's *2012 ZEV Action Plan* targets 1.5 million zero emission vehicles on California's roads by 2025 (Brown 2012). These objectives also motivated California Energy Commission's co-funding of the L.A. AFB project.

More recently, the potential for localized power systems, or microgrids, to provide high quality reliable power to installations, such as military bases and communities, has become increasingly recognized. Since smaller power systems require storage even more than larger ones because loads do not even out as much, the potential of PEVs to support microgrids has become an area of intensive research (Stadler 2012, Marnay and Lai 2012).

The U.S. Defense Deparment (DoD) is under various mandates to introduce electric vehicles into its fleet. Executive Order 13423 requires Federal agencies, based on a baseline of fiscal year 2005, to (i) reduce their fleet's total consumption of petroleum products by 2 percent annually, (ii) to increase non-petroleum-base total fuel consumption by 10 percent annually, and (iii) to use plug-in hybrid vehicles when available at a reasonably comparable cost. A section of the U.S. Code requires DoD to prefer the lease or procurement of motor vehicles using electric or hybrid propulsion systems, if cost comparable. Also, a Presidential Memorandum on Alternative Fuel Vehicles (24 May 2011) says by 31 December 2015, all new light duty vehicles leased or purchased by agencies must be alternatively fueled. Further, a pending DoD directive on PEVs establishes goals for procurement, identifies V2G as a key technology for development, and sets roles and responsibilities for military services and defense agencies.

Despite the many facets of ongoing PEV research and the overall desirability of fleet electrification, it is not surprising the L.A. AFB demonstration is focused squarely on participation in the CAISO Reg.U+D markets. Regulation markets have often been proposed as a source of AS revenues potentially able to ameliorate undesirable PEV ownership economics (Kempton and Tomic 2005, Lipman 2009, Williams and Lipman 2010). While this project poses substantial technical challenges, it is nonetheless an essentially economic issue being explored, i.e. to what extent, if at all, the differential between the cost of ownership of a PEV fleet and a conventional ICE one can be reduced by participation in a highly complex V2G opportunity, namely, the CAISO Reg.U+D markets.

Project description

Overview

During 2013, a small (≈ 40 vehicles) fleet, each PEV with at least one compatible electric vehicle service equipment (EVSE or charging station), is being deployed as an all-electric fleet pilot at the L.A. AFB. Anticipating a broader DoD non-tactical fleet electrification program, this phase one pilot is intended to unearth challenges of installing and operating PEV fleets. The next two phases of the program have already been announced; the second involves approximately 500 medium duty trucks at six military bases, including L.A., and the third phase will expand the PEV fleet to approximately 1,500 vehicles. The entire program will include V2G activity.

At the L.A. AFB, the DoD will explore the technical challenge of bidding the fleet into the CAISO Reg.U+D markets. As explained below, these markets generate the most revenues together, i.e. PEVs must be able to discharge into the grid, i.e. have bidirectional power flow capability. Normal fleet management tools will be augmented by three additional capabilities.

1. Bosch's PEV management software suite, eMobility Solution, will provide vehicle users and fleet managers with powerful and convenient additional functions, and manage charging-discharging.
2. OpenADR technology will permit V2G participation in AS markets. OpenADR will be used to send instructions received from CAISO at a secure Akuacom DRAS, and then to eMobility, allowing Reg.U+D response within the 4 second time limit required by CAISO. CAISO does not deal directly with market participants; rather, each must be represented by a scheduling coordinator (SC). Further, in this case it may be required to be the local electricity distribution utility, Southern California Edison (SCE).
3. A near real-time optimization system will be set up that merges Berkeley Lab's microgrid optimization tool, the Distributed Energy Resources Customer Adoption Model (DER-CAM), with the two other capabilities mentioned to form PEV-fleetOPT (Marnay et al 2013). This combined technology will forecast grid energy and AS prices, weather and other variables, and together find optimal charge-discharge schedules (CDSs) for available interconnected PEVs delivered to fleet operators and EVSEs via eMobility Solution's user tools.

L.A. AFB project objective

The potential payoff from replacing the DoD's approximately 200 000-vehicle conventional non-tactical fleet by electric vehicles has been carefully investigated and shows great promise. Nonetheless, effective operation of an all-electric fleet, especially capturing all the potential economic and surety benefits, requires sophisticated systems employing expertise across a broad range of disciplines, including electrical engineering and power systems, communications and IT, logistics and operations, regulation and law, and perhaps most importantly, economics. At first blush, the latter represents the biggest challenge because currently electric vehicles are more expensive to operate over their life cycles. This project aims to gauge the extent to which cost-minimizing charging and electricity grid service provision revenue can narrow the gap between the costs of a conventional fleet and a similar PEV fleet. The PEVs at the L.A. AFB will have additional fleet management and operational optimization tools to ensure that the complex task of scheduling charging-discharging of vehicles can be achieved such that energy costs are minimized. Additionally, the benefits from participation in grid AS markets, especially regulation support, will be fully captured by submitting the best possible overall bids and executing the best possible scheduling. Receipt and fast response to grid instructions will be enabled through use of the OpenADR protocol to pass instructions between the fleet and CAISO. These capabilities, together called PEV-fleetOPT, will facilitate economically optimal operation of the demonstration fleet. Results will be used to assess the overall economic viability of DoD non-tactical fleet electrification.

Base description

The L.A. AFB is a commercial facility with approximately 90 000 m^2 of office space and a combined peak electrical load of approximately 4 MW. Despite being an AFB, it has no runway and no aircraft, its mission being management of defense contracts with the nearby aerospace industry. Note the Northrop Grumman factory along the left edge of Figure 1. The base lies 2 km south of the southeast corner of the L.A. International Airport, which is where the Cities of El Segundo and L.A. meet, and also where the SCE service territory meets that of the L.A. Department of Water and Power (LADWP). Figure 1 shows the base, with its northern perimeter to the left. The fleet dispatchers' building, where the PEV-fleetOPT server will be installed, lies near the northwest corner. The building to the east is a small warehouse, and further east two buildings have been demolished to

create the PEV parking area. This picture does not show some of the important more recent features, notably a large (300 kW) canopy PV array in the parking lot still further east, shown in Figure 2 below. Also shown is a picnic area seen in the aerial view along the right (south) edge. A parking structure with planned ground mount PV nearby has also been constructed west of the dispatchers' building, and various other rooftop arrays have also been recently installed.

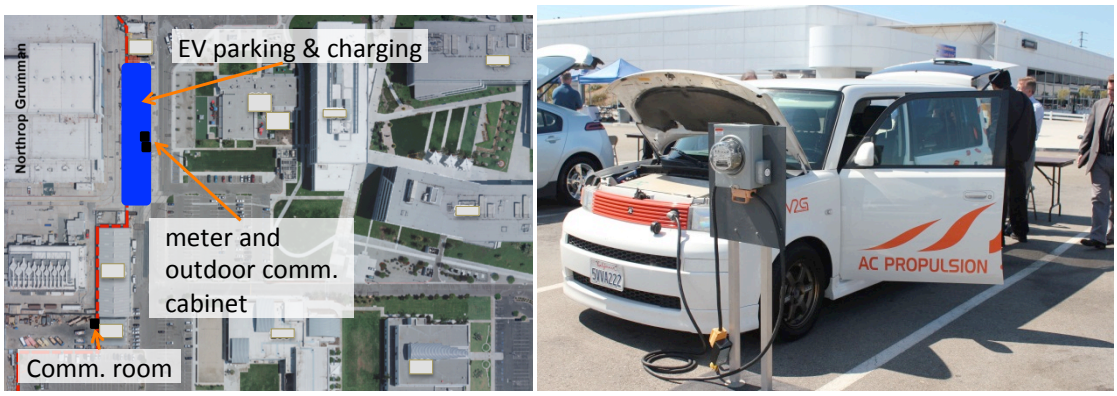

Figure 1. Aerial view of L.A. AFB left and a V2G capable sedan right

While climate is only marginally important to the project, the temperate California location offers some benefits and some potential negatives, e.g. good battery performance but coupled with frequent air conditioning use. An aspect of location of great importance, however, is the institutional context it implies, notably the local electricity utility service territory. Were the base in LADWP territory, which is a municipal utility not within the CAISO footprint and not regulated by the CPUC, the project could be quite different. This aspect is noteworthy because regulatory barriers to the project have been one of the major problems experienced to date; however, it should be noted that absent open CAISO AS markets to provide revenues, the economics of the project would be dependent on less transparent bi-lateral contracts.

Figure 2. L.A. AFB PV canopy left and base central plaza right

This base is fairly atypical in size, function, and vehicle fleet; nonetheless, it offers an instructive test opportunity for other powerful reasons: manageable base and fleet size, favourable climate and access, within the territory of an electricity distribution company within CAISO with its open AS regulation markets, and readily accessible from L.A. International Airport.

Timeline and challenges

1. The project began in February 2012.
2. The basic interfaces between the elements of the combined software package were developed over most of 2012.
3. Resolving the regulatory and technical details of market participation has consumed the largest share of time and effort over the latter half of 2012, and this will likely continue well into 2013, causing discouraging delay in the project schedule. A significant fundamental source of these difficulties is the potentially contradictory role of the base as both a *retail* energy customer in SCE territory and a participant in CAISO's *wholesale* markets. This situation requires participation and approval by several institutions, the AF and DoD, SCE and its regulator the California Public Utilities Commission, CAISO and its regulator the Federal

Energy Commission (FERC), not to mention the authors as humble researchers and our funders and institutions. Some of these challenges are due to the many firsts this project entails. Future ones should proceed more smoothly, at least in California and certainly in the SCE service territory.

4. Meeting the requirements for cyber security on a military base has been the second major difficulty. The system architecture was carefully designed to lie entirely outside the base firewall and use its own internet service provider (ISP) access. Installation of a beta version of the fleet management software on a dedicated server outside the base firewall was scheduled for installation on the base by the end of 2012, but complications obtaining permission to deploy the necessary hard and software has delayed installation until approximately the end of March 2013 at best. The intent was to use the beta software with the existing conventional fleet, but this could not be commenced. The fundamental problem has been understanding and complying with the convoluted and rigorous processes needed for approvals.
5. Because of delays in installing at the base, most basic interfaces within PEV-fleetOPT will be established early in 2013 and will be demonstrated at a temporary set-up at Berkeley Lab, which is a much less satisfactory arrangement.
6. Upon system installation, terminals will be made available for dispatchers to use a beta eMobility system for their normal activities with the conventional fleet, which will also serve as a data collection tool.
7. Development during the first half of 2013 will confront the most difficult programming challenges, related to managing the fleet and updating bids and schedules in real-time, given changing conditions, incorporating uncertainty and preparing for contingencies, particularly emergencies.
8. PEVs should arrive in mid-2013. The difficulty of procuring vehicles and EVSEs with the V2G capabilities required has been the third major challenge of the project so far. The goal of operating a mixed duty fleet has resulted in few of each type of vehicle being required, limiting options and raising complexity and costs. After testing, the current path to full market participation approval would allow market entrance at the beginning of August 2013. A formidable challenge will be having enough PEVs available by then to meet CAISO Reg.U+D market minimums, which are 1. proven 500 kW of continuous charging-discharging capability for a full hour, 2. 100 kW on-line at all times of market participation, and 3. minimum bid steps of 10 kW.
9. All available vehicles will be operated through the end of 2013.
10. The major project will be shut down in early 2014, and reporting will be completed, but other activities with the fleet will likely continue through 2015.

Technology description

Overview

Figure 3 provides an overview of PEV-fleetOPT. Bosch's eMobility Solution components, shown in light blue, sit at the heart of the system. eMobility is functionally divided into its *Fleet Services* and *Charging Services* components. The Fleet Services part provides the central software system to be used by fleet dispatchers. Fleet Services schedules all the different requests placed on the vehicle fleet, and collects data on the fleet, notably the availability and technical status of the fleet, e.g. the battery state of charge (SOC), which are the key inputs to the DER-CAM optimization shown bottom right. The Charging Services part communicates individually with all participating EVSEs, up to 40 in this project, and controls charging-discharging of the PEVs according to optimal schedules provided by DER-CAM. Further, eMobility exchanges information via the OpenADR client software with the DRAS, receiving instructions from CAISO and passing bids and other information to CAISO.

OpenADR implementation

Akuacom's DRAS and OpenADR technology, shown in light green, provide communication outside the L.A. AFB. OpenADR standards offer an open standardized technology for electricity distribution entities and system operators to communicate grid signals with customer sites using a common language over any existing IP-based communication network. As the most comprehensive standard for Automated Demand Response, OpenADR has achieved widespread support throughout the industry. Four major communication links permit the base's participation in Reg.U+D markets.

1. The all-important bids for provision of Reg.U+D by the fleet derived by DER-CAM are passed to the base's scheduling coordinator (SC), which is the only entity from which CAISO will accept the bids. Given the net-metered implementation of the wholesale resource and the lack of precedent for a Wholesale Distribution Access Tariff to include Reg U+D, SCE will likely act as the base's SC in the Reg.U+D markets, but this has not yet been determined. There are two types of Reg.U+D bids, day ahead (DA), which must be submitted to CAISO for tomorrow by 10:00 today, which may mean earlier delivery to the SC, e.g. by 7:00. These are the

most important bids, both because this market is most lucrative and because they are imposing constraints on the following day's fleet operations. The DA bids must be based on reliable forecasts and be resistant to operational uncertainty. There is also an hour ahead (HA) market, which could be useful for rectifying errors. These bids must be submitted 75 min before the hour of the service offer. However, the HA market is less lucrative, and useful more as a correcting or hedging opportunity.

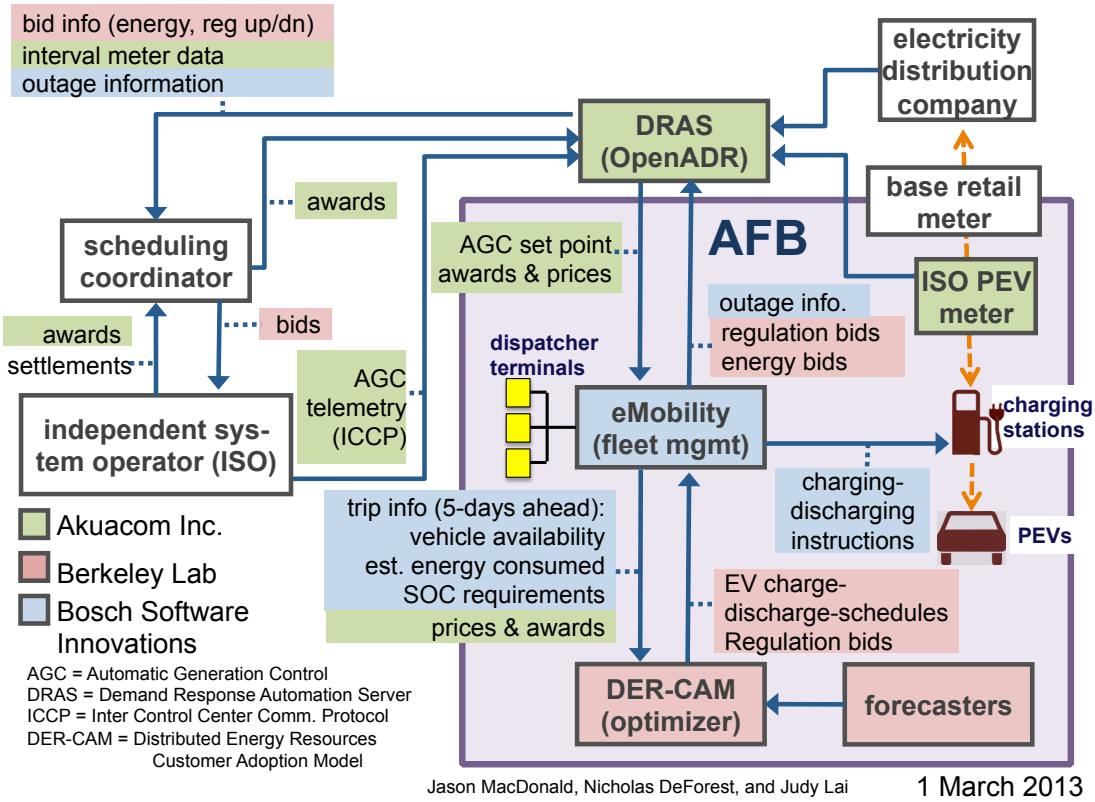

Figure 3. Data flows in PEV-fleetOPT

2. Returning from CAISO via the SC are awards on the acceptance of bids. On a much slower time scale, settlement details will also be passed.
3. Most importantly, instructions from CAISO to implement the AS through time must be delivered by CAISO approved telemetry. These instructions occur on 4-second ticks. Response must happen by the following tick, and be verified by the one after that. In other words, round-trip latency between an instruction leaving CAISO and its receipt of response verification must be < 8 seconds total.
4. CAISO has rigorous and specific metering requirements. A dedicated meter with a dedicated communications path for its data will also be provided by Akuacom.

Fleet management

Fleet services

Fleet Services reports the availability of the complete fleet as planned by the dispatchers as they use the software tools for their normal activities. The software must also allow for last minute changes to the vehicle scheduling, which might have substantial disadvantages or might even cause penalties based on the compromised participation in the Reg.U+D markets. Also, the software is comparing the planned operations with the execution of trips. If the planned and actual values differ, the software automatically adapts the planned value, considering the given constraints like SOC and time. Fleet Services follows the integrated business process management approach for planning, analysis, design and implementation.

Charging services

Charging Services' activities are influenced by both the vehicle schedule provided by the dispatcher and the energy schedule provided by DER-CAM. Based on both inputs, the Charging Service module sends the appropriate signal to each individual EVSE, starting charging, stopping charging, starting discharging or stopping discharging of each currently connected and available vehicle. The extent to which variable charging is possible will depend ultimately on PEV and EVSE capabilities, as will availability of basic pieces of vehicle and charging station data. This exchange includes but is not limited to critical data, such as vehicle identification number, mileage, SOC, etc. This data can be communicated using the Open Charge Point Protocol (OCPP), or Bosch's own protocol, but there is a strong preference for using the emerging OCPP standard. In any case, V2G capabilities must be added to existing communication protocols.

The California regulation market

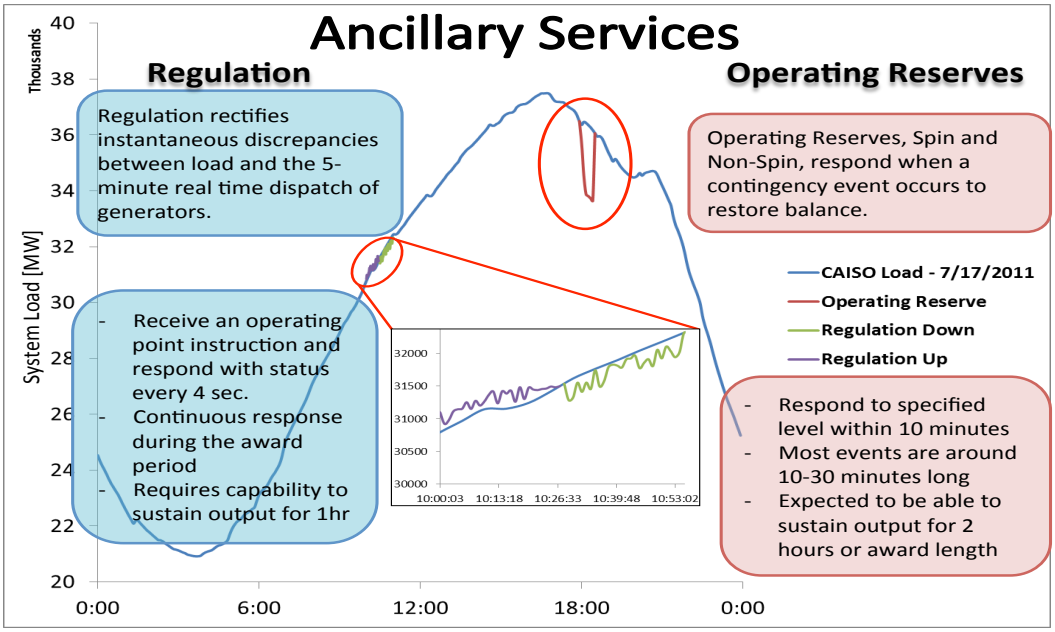

Figure 4. CAISO's ancillary services markets

PEVs and regulation markets

The battery packs of PEVs offer a potentially valuable resource because all power systems of all sizes crave storage capacity to even out production of electricity, i.e. storing energy in low cost periods and discharging it in high cost ones. PEVs can certainly provide this service to significant benefit, most likely to the buildings where they are charged, but the energy storage available in PEV batteries is limited and costly, and additionally, offering it to the grid interferes with operational requirements. Consequently, while energy-based opportunities will be studied in this project, they are not the focus of the effort, which is on capacity-based grid AS provision. PEV batteries can charge and discharge at substantial rates of power, and critically, they can respond quickly. Because most alternatives available to grid operators cannot respond so readily, offering fast response regulation service is lucrative, and does not require substantial storage capacity.

Figure 4 shows the AS requirements of CAISO. AS at the control level are basically stand-by resources that system operators can call upon when conditions deviate from those they have planned for, e.g. because of forced resource outages or small supply-demand balance fluctuations. The more obvious contingency is shown in the upper right of the figure. Loss of a major resource, e.g. a power plant forced outage, creates a generation shortfall that must be rectified for the system to survive possible subsequent problems. As explained above, PEVs are not well suited for providing this service because they cannot economically store enough energy to discharge at high power for the duration required, typically a few hours. The service shown on the left of the figure much better matches the capabilities of PEVs. In addition to the large back-up resources ISOs require, they also need fast responding ones that they can continuously adjust to iron out the tiny discrepancies that occur between resources and loads. And in fact, since these excursions go in both directions, the net energy they need to deliver can be low or negative, which makes it a much more attractive proposition for PEV fleets and the target of this demonstration. Note that planned battery charging can be accelerated or slowed and batteries can additionally be discharged, thereby providing Reg.D (increasing system load) or Reg.U (increasing system generation).

CAISO markets

CAISO has separate competitive markets for trading energy and each of its AS. These markets operate at three different timescales: DA, HA, and Real-Time. The AS markets are voluntary bid-in markets in which all successful bids are paid the Market Clearing Price (MCP), or the highest accepted bid for the award period. The DA Market (DAM) is where 100% of the forecasted AS needs are procured. Bidding for the DAM closes at 10:00 on the day prior to the operating day, and awards are for full hour-long timesteps. The HA Market closes the bidding 75 minutes before the operating hour and makes awards in 15 minute intervals. The Real-Time Market uses the HA bid and dispatches every 15 minutes for AS. Fifteen-minute awards are given 7.5 minutes in advance, and aims to meet shortfalls in AS capacity in real-time. The vast majority of AS capacity is awarded in the DAM and its prices are higher, which makes offering the best possible DA bids a critically important analytic and programming challenge.

The four AS [Reg.U, Reg.D, spinning reserves (SR), and non-spinning reserves (NSR, S+NSR for both)] procured in CAISO's competitive markets can be thought of as capacity products, meaning that when a resource is awarded, they are promising to hold their generating capacity in abeyance for use by the ISO in the event that they are needed. As noted above, regulation (both up and down) is used to balance instantaneous mismatches between electricity supply and demand. Resources providing regulation set aside their awarded capacity to be continuously controlled by the system operator through automatic generation control (AGC) signals delivered every 4 seconds. S+NSR are capacity that is set aside to respond to CAISO requests for energy either as imbalance energy or exclusively for contingencies. The seller of S+NSR reserves designates whether the associated energy is available for the imbalance energy market or contingencies only. Imbalance energy is dispatched every 5 minutes with notification 2.5 minutes in advance, and contingency energy within 10 minutes following an event, such as the loss of a generator. In CAISO, contingency reserves are deployed sparingly, only around 25 times per year (Kirby 2007). These sources are expected to provide a response for up to 30 minutes (CAISO 2012c), although most events are over in less than fifteen minutes. The Western Electricity Coordinating Council (WECC) is the regulatory body that ensures grid reliability and governs electricity balancing authorities in the Western U.S., Canada, and a part of Mexico. Currently, WECC does not allow non-generating resources to provide any AS to the grid except NSR (WECC 2007). WECC has recently gone through a balloting process and approved a new standard that will allow demand response and other non-generator resources to provide all AS (WECC 2012). This new standard must still be approved by FERC before it goes into effect. This confused regulatory picture has been one of the sources of delay and difficulty for the project. CAISO must choose a suitable model for PEV fleets from its existing markets suitable for V2G, obtain FERC approval for a pilot demonstration using it, and update its software accordingly. The latter constitutes a substantial task for an ISO managing multiple open markets.

Market analysis approach

The CAISO AS markets were analyzed using a series of statistics and graphics generated from hourly AS prices and capacity procurement data. The AS MCPs were obtained using the Velocity Suites database, which obtains its data from CAISO directly (Ventyx 2012). The pricing units are denoted as $/MW-h, where MW-h represents a MW of power capacity held for an hour. The hourly AS capacity procurement data was taken from CAISO's Open Access Same-time Information System (CAISO 2012b). Three years of hourly data were collected from 1 April 2009 to 31 March 2012 and analyzed using Matlab®.

There are two major AS market regions in CAISO, North and South of Path 26 (NP26 and SP26), which are sometimes labelled as CAISO North and CAISO South. Path 26 refers to a major axis of congestion that divides the state's grid because of the dividing line between the historically separately operated grids of Pacific Gas and Electric in the north, and SCE in the south. Prices for generators in Southern California will generally be greater than or equal to the prices in the north. Additionally, prices for imported AS are always less than resources within CAISO. Its complex formula for the official market price derives an expanded system price, adds a shadow price for units inside the balancing area determined by relaxing congestion constraints, and then adds a shadow price for units in the southern portion of the balancing area. The region in which a unit resides in determines which shadow prices are summed together, but the summed prices (greater than the expanded system price) are paid only when CAISO determines that sub-regional procurements are required.

Day-Ahead Market

Table 1. Day-Ahead Market Clearing Prices Statistics for CAISO South from April 2009 – March 2012

	Average [$/MW-h]	Std Dev [$/MW-h]	Min [$/MW-h]	Max [$/MW-h]
Regulation Up	8.75	9.33	0.00	545.27
Regulation Down	6.73	5.45	0.00	79.55
Spinning Reserve	6.25	7.81	0.00	440.92
Non-Spinning reserve	0.91	4.17	0.00	416.33

Table 2. Equivalent prices for CAISO North

Average [$/MW-h]	Std Dev [$/MW-h]	Min [$/MW-h]	Max [$/MW-h]
6.59	7.25	0.00	416.94
5.60	4.75	0.00	79.55
4.81	6.60	0.00	416.37
0.90	4.14	0.00	416.33

The MCP for AS provides an indicator of the potential revenue that a PEV or other AS provider could extract from the market. Table 1 and Table 2 show price statistics for the four AS traded in CAISO's DAM for the years 2009-2012. The prices in Table 1 are representative of generators in CAISO's SP26 reserve zone, while those of Table 2 are for generators in NP26, the former being generally higher. Reg.U is the most lucrative on average but with significant variance around the mean. The maximum value of regulation in CAISO South is high, at 545.27 $/MW-h. The average price of Reg.D and SR were nearly the same, with Reg.D being more stable. It should be noted, however, that a generator can be awarded both Reg.U and Reg.D at the same time, making it worth only 40% of the value of combined regulation awards.

The spring months, followed closely by the summer, are the most lucrative for Reg.U+D and SR. Spring revenues for Reg.U+D and SR are high because the snowmelt delivers a surplus of water to hydro dams, requiring them to generate rather than holding back their capacity for AS. Consequently, a larger percentage of AS are supplied by thermal units leading to higher prices. The tables above indicate that providing both Reg.U and Reg.D is most lucrative. Note that a vehicle will need a 15 kWh buffer both in charging-discharging capacity to provide 15 kW of Reg.U+D. In other words, careful management of the SOC is required to maximize AS revenues. If keeping the battery at a nearly full charge all of the time is desired, then providing SR becomes more appealing. This service has less demanding requirements yet is valued at around 75% of that of Reg.U, although it does risk vehicles being discharged at inopportune times.

Examining averages over the three-year period is valuable, but it does not clearly indicate any long-term trends. Figure 5 attempts to illustrate trends by showing how the monthly average Reg.U prices in CAISO South moved over time. There is no clear overall trend; however, the average tended to increase during the spring and summer during both 2010 and 2011. In 2011, the clear considerable price increase was caused by high rainfall. Hydro-electric plants reached their storage capacity, and were forced to be more active delivering energy to the electricity grid than providing AS. The departing hydro leaves other more expensive capacity CAISO's most economical AS choices raising MCPs (CAISO 2012a). The other two lines plotted show the minimum MCP and the 95th percentile each month. The spread between the plots indicates that the spring and summer months are more volatile than others. SR and Reg.D prices show similar seasonality. Reg.U prices tend to be higher in high load times, and Reg.D in low load times, as one would expect, although again there is significant variability.

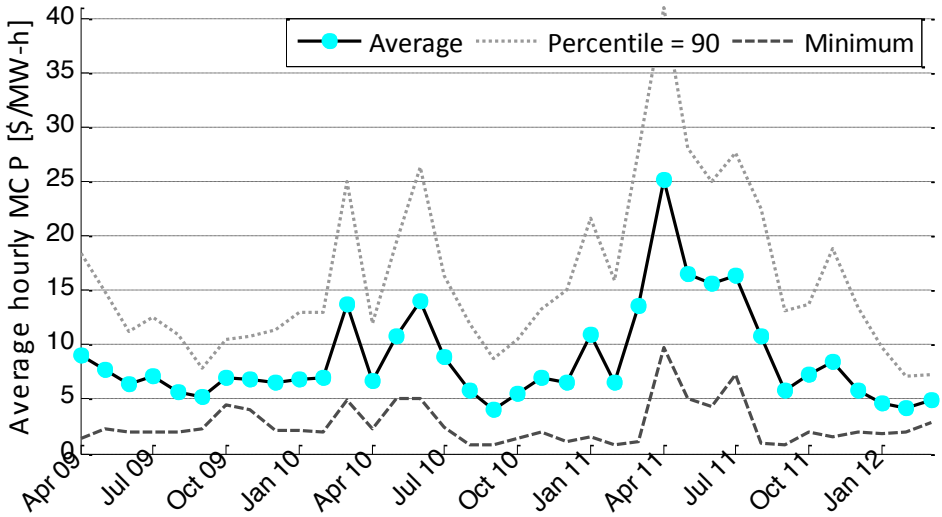

Figure 5. Monthly Average Market Clearing Prices for Regulation Up in CAISO Markets 4/2009-3/2012

While monthly averages can indicate overall trends, the daily dynamics of MCP have a large impact on resource utilization. The afternoon and evening hours deliver the most revenue for Reg.U and the least for Reg.D, and vice-versa during the early morning hours. These relationships could have an interesting effect on the way a vehicle would be optimally charged while simultaneously providing Reg.U+D.

The charging capacity for V2G capable EVs can be bid into the Reg.D market; however, if a vehicle is scheduled to charge for a specific period, only the remaining charging capacity (its total capacity minus its current charge level) is available for bid. The capacity available for Reg.U (interrupted charging plus discharging capacity) may reach the PEV's maximum charging level. Nonetheless, providing capacity for Reg.U in the middle of the day, especially between 15:00 and 18:00, could be much more lucrative and should be pursued if possible. This argument does not reflect energy prices, which may oppose the revenue generated through AS based schedules, so that must be accounted for during the development of optimal vehicle charging schedules. The need to simultaneously consider all of these factors, and based on uncertain forecasts, find optimal schedules explains the project's emphasis on optimization capability.

Market size

Table 3. Market size for AS for CAISO South

CAISO South	Average Hourly Market Size [$/hr]	Annual Market Size [M$/yr]	
		2010	2011
Regulation Up	890	6.20	11.00
Regulation Down	665	5.79	7.11
Spinning Reserve	1,460	11.16	18.62
Non-Spinning Reserve	316	1.88	3.07

Table 4. Annual market size for AS for CAISO North

CAISO North	Average Hourly Market Size [$/hr]	Annual Market Size [M$/yr]	
		2010	2011
Regulation Up	665	6.48	7.11
Regulation Down	558	5.09	5.11
Spinning Reserve	1,584	13.89	18.37
Non-Spinning Reserve	237	1.23	2.56

It is important to understand how much money is on the table when considering the viability of a complex new technology as being demonstrated in this project. Market size for each resource was computed for each hour by a simple product of that hour's price and capacity procurement. The average hourly market size and the total

annual market size for each AS are reported in Table 3 and Table 4. The combined Reg.U+D markets are roughly the same size as the SR markets in Southern California, while NSR is considerably smaller than both. However, in Northern California, there tends to be more money in the SR market than the Reg.U+D, which may reflect the considerably higher percentage (15-30% more) of procurement that occurs in the market (not self-supplied) than the other AS in the North. The increase in market size between 2010 to 2011 resulted from a high rainfall induced price increase.

An initial study of fleet vehicle schedules at L.A. AFB suggests maximum likely monthly revenue from Reg.U+D participation could total approximately 100 $/mo. While not a princely sum, this would be enough to move the economics of fleet PEV operation. A typical sedan now leases for 250-350 $/mo. Initially it appears that the annual market size is not large. If a vehicle is hoping to earn approximately 100 $/mo providing Reg.U+D, the market can support only a maximum of approximately 10-15 thousand vehicles, without considering the effect of that number of vehicles on prices. This implies that providing these V2G services may be a good way to help promote the purchase of early PEVs, but may have little impact in a mature market. Counter to this argument, many anticipate that the higher renewables penetration of future grids will increase AS requirements (Helman 2010). Conversely, it should be noted that future variability in power systems may be addressed by more localized means, e.g. within locally controlled microgrids, thereby relieving ISOs of some of their AS procurement obligations.

Conclusion

The DoD is under legislative mandate and Executive Order direction to electrify as much of its non-tactical fleet of approximately 200 000 vehicles as is economic. A significant unknown in the implied cost equation between PEVs and conventional vehicles is the revenue potential of V2G opportunities, such as CAISO's Reg.U+D markets. To explore this question, an entire test fleet at L.A. AFB will participate in CAISO's Reg.U+D markets using a sophisticated fleet management, communication, control, and optimization technology package, known collectively as PEV-fleetOPT.

PEV-fleetOPT is still under development, so it remains too early to say what L.A. AFB bids and charge-discharge schedules will look like. Early results suggest the aggregate state of charge will be fairly constant. Vehicles are recharged during the morning until 13:00. In other words, keeping the state of charge at a point favorable for AS market participation seems a strong objective, dominating the high daytime electricity prices. In general, the PEVs are offered into the market whenever they are available, with more action in Reg.U, being more lucrative. Because most trips take place during the morning and early afternoon, the vehicles need to be kept charged during the morning; therefore, Reg.D is bid much less before the day's trips than afterwards.

The general pattern seen in the global status of the fleet is reasonable and surprisingly stable, but the global consistency doesn't necessarily translate into simplicity at the individual vehicle level. In fact, charging-discharging schedules of individual vehicles tend to be quite complex. Again, these are early results, but they suggest that bidding will be active, and potential market revenues will trump high energy costs in scheduling.

The project remains on track to demonstrate the technical feasibility of the objective, but the project has encountered problems in three major areas.

- DoD considers it an accounting essential that all settlements appear on its one base utility bill, making evaluation of the project accurate and permitting redirection of savings. This poses a challenge for SCE particularly because it is not within their purview to support projects of this type without pilot funding, nor do they typically combine seemingly unrelated credits onto customer bills. The contradictory role of the base as both a retail SCE energy customer and simultaneously a participant in CAISO's wholesale markets poses an unusual regulatory conundrum. This situation requires participation and approval by several institutions, the AF and DoD, SCE and its regulator the California Public Utilities Commission, CAISO and its regulator FERC, not to mention ourselves as humble researchers and our funders and institutions.
- Meeting the requirements for cyber security on a military base has been a major stumbling block. A beta version of the fleet management software was scheduled to be installed at the base on a dedicated server outside the base firewall by the end of 2012, but obtaining permission to deploy the necessary hard and software has delayed installation to the end of March 2013 at best. The fundamental problem has been understanding and complying with the convoluted and rigorous processes needed for approvals.
- Not surprisingly, the difficulty of procuring vehicles and EVSEs with the technical capabilities required has been the third major challenge. Obtaining equipment from vendors willing to customize for this demonstration is an ongoing problem, particularly since V2G will require significant enhancement of PEV and EVSE communication capabilities and protocols, in addition to the bi-directional power flow requirement.

If the PEV energy consumed is fully billed under a retail tariff, the implications this usage pattern may have on the base's electricity bill, especially demand charges, remains unclear. Based in the information currently available, it's simply not possible to know when significant forced energy purchase or sale will occur. For example, vehicles providing regulation may be commanded by CAISO to consume or release energy at the same time the base is setting its monthly demand charge, resulting in a higher/lower bill (up to an additional 500 kW for example). There are three different options that may be pursued to mitigate this risk. First, demand from the vehicles could be subtracted from the base's other load when setting the demand charge. This separation may decrease or increase the base's demand charges, but the former seems more likely as Reg.U (more lucrative in afternoon hours) would provide a net decrease in the base's metered load. A second option is to just leave this risk to be included in the charge-discharge optimization, and no change to the base's tariff is necessary. For example, this might push the optimization towards providing a negative price bid in certain hours, since being called for regulation up at a negative price could lower the demand charge enough to cover the loss. Thirdly of course, energy settlement could all take place through CAISO, but this would still require metering by SCE to cover distribution costs. If the base remains on a retail tariff, these incentives could affect wholesale market participation, as bidding may incur risk or benefits in some hours of the day. A retail tariff does give the base more flexibility, as it could potentially use its fleet for both V2G and vehicle to building (V2B) applications. One challenge to this approach is the amount of uncertainty that exists in the AGC instructions. At present it remains quite uncertain how these vehicles will be exercised by the CAISO. While the maximum bill impact, e.g. a 500 kW change in the demand charge(s), the likelihood of such an outcome is currently unknown. There is no public AGC data available, and there is limited information on the algorithms that govern the CAISO's EMS instructions. Cursory exploration of whole system regulation data has suggested the system tends to charge on average, but no information on a comparable battery resource, and CAISO's market simulations to date have not been realistic in this regard.

An analysis of the Reg.U+D markets suggests that a successful program may be able to generate about $100/month/vehicle of revenue from these markets, which is significant. However, the cost and complexity of system required to participate in V2G suggest that developing a cost effective system poses a major challenge. Specifically, the equipment and operational costs of V2G participation will quickly erode the $100/mo of revenues. As one example, currently, direct CAISO access to its on-base meter via its private Energy Communications Network alone costs up to $500/mo, suggesting under some scenarios 4 PEVs would be participating in the market simply to cover communication costs to their meter. Luckily, this project has secured a CAISO waiver allowing much cheaper dial-up meter reading. It is worth noting that there are many other aspects of the cost structure of a production resource in the wholesale market that need to be evaluated beyond these infrastructure costs.

Finally, some key insights generated from the market analysis discussion are:

- The most lucrative markets are DA Reg.U+D. For the three years beginning April 2009, the SP26 DA Reg.U and Reg.D markets had average hourly MCPs of $8.75/MW-h and $6.73/MW-h respectively. Additionally, a resource may be awarded both simultaneously, making participation in those markets approximately 2.5 times more valuable than SR, which in any case is not a good technical fit for PEVs.
- The annual combined SP26 market size for Reg.U+D is approximately 11 to 17 M$. Thus, CAISO would be able to support only 10-15 thousand PEVs with no other market participants, if vehicles are hoping to make $100 per month. Nonetheless, future trends in CAISO AS procurement are uncertain, with many parties rushing to acquire these lucrative revenues.
- Reg.U+D seem to have complementary daily MCP profiles in some seasons. These variations should lead to more significant gains through bidding capacity and vehicle charging optimization.
- The most CAISO Reg.U+D market income a PEV with 15kW bi-directional V2G capability can expect lies between $102-122 per month, depending on the vehicle's availability, SOC, and precision of CDS execution. These numbers do not consider the costs of bidding into the markets.
- Available V2G charging power capacity constitutes the most important factor determining income from AS markets. This makes fast charging, e.g. fast DC charging-discharging capability highly desirable. Nonetheless, given its high cost, clearly a trade-off must be made, especially since fast charging might also require infrastructure upgrade.

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Glossary

AF	U.S. Air Force
AGC	automated generation control
ALC	Automated Logics Corp.
AS	ancillary services
BACnet	communication protocol for building automation and control networks
CAISO	California independent system operator
Cat5	Category 5 copper Ethernet wire
CDS	charge-discharge schedule
CEC	California Energy Commission
COLO	collocated commercial services, i.e. server farm or data center
CPLEX®	IBM ILOG CPLEX Optimization Studio, optimization solution package
CPUC	California Public Utilities Commission

DA	day ahead, especially markets requiring bidding today for services delivered tomorrow in hourly intervals
DAM	day ahead market
DR	demand response
DER-CAM	Distributed Energy Resources Customer Adoption Model
DoD	U.S. Department of Defense
DRAS	Demand Response Automation Server
DSL	digital subscriber line
ECN	electronic communication network
ESTCP	Environmental Security Technology Certification Program
EVSE	electric vehicle service equipment, or charging stations
FERC	Federal Energy Commission
FW	firewall
GAMS®	General Algebraic Modeling System
HA	hour ahead, bidding now for services delivered 75 min hence, in 15 min intervals
ICE	internal combustion engine
ICCP	Inter Control Center Protocol
ISO	independent system operator
ISP	internet service provider
IT	internet technology
L.A. AFB	Los Angeles Air Force Base
LADWP	L.A. Department of Water and Power
LBNL	Lawrence Berkeley National Laboratory (also Berkeley Lab)
MCP	market clearing price
MW	megawatt
NP26 and SP26	north and south of Path 26, the congested corridor that divides California
NSR	non-spinning reserve
OpenADR	NIST adopted protocol for delivering grid instructions to loads
OCPP	Open Charge Point Protocol (http://www.ocpp.nl/)
PEV	plug-in electric vehicle
PEV-fleetOPT	combined capabilities demonstrated in this project
PV	photovoltaic power generation
Reg.U+D	CAISO Regulation Up and Regulation Down AS markets, Reg.U and Reg.D separately
RIG	remote intelligent gateway
SC	scheduling coordinator, required to participate in CAISO markets
SCE	Southern California Edison, local L.A. AFB electricity utility
SOC	state of charge
SR	spinning reserve
S+NSR	spinning and non-spinning reserve
V2G	vehicle to grid, i.e. provision of grid services by vehicles
VPN	virtual private network
WECC	Western Electricity Coordinating Council

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