# Eaton High Impact Project

## Cooperative Research and Development Final Report

## CRADA Number: CRD-18-00748

NREL Technical Contact: Kate Anderson

**NREL is a national laboratory of the U.S. Department of Energy**
**Office of Energy Efficiency & Renewable Energy**
**Operated by the Alliance for Sustainable Energy, LLC**

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Contract No. DE-AC36-08GO28308

**Technical Report**
NREL/TP-5C00-83929
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# Cooperative Research and Development Final Report

**Report Date:** September 1, 2022

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

**Parties to the Agreement:** Eaton Corporation

**CRADA Number:** CRD-18-00748 (Project 1 and Project 2)

**CRADA Title:** Eaton High Impact Project

**Responsible Technical Contact at Alliance/National Renewable Energy Laboratory (NREL):**

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**Name and Email Address of POC at Company:**

Chris Herbst | ChristopherAHerbst@Eaton.com

**Sponsoring DOE Program Office(s):** Office of Energy Efficiency and Renewable Energy (EERE)

**Joint Work Statement Funding Table showing DOE commitment:**

| Estimated Costs | NREL Shared Resources a/k/a Government In-Kind |
|---|---|
| Year 1 (Project 1)<br>Year 2, Modification #1 (Project 2) | $250,000.00<br>$0.00 |
| TOTALS | $250,000.00 |

**Executive Summary of CRADA Work:**

The NREL team will partner with Eaton to evaluate control strategies for managing Electric bus (E-bus) fleets for grid services. NREL will develop a replicable platform for evaluating EV fleet management and quantifying benefits from grid services. The proposal will cover the technology areas of solar, energy storage, mobility, and buildings.

**CRADA benefit to DOE, Participant, and US Taxpayer:** Uses the laboratory's core competencies.

## ORIGINAL AGREEMENT, PROJECT

### Purpose and Overview

NREL will develop a replicable platform for evaluating EV fleet management and quantifying benefits from grid services. The proposed project will develop and evaluate control strategies to optimize mobility, solar, building load and storage assets at a site. The outcome of the project will be a co-optimization framework for optimal integration of mobility with other DER technologies. An overview of the project is provided in Figure 1.

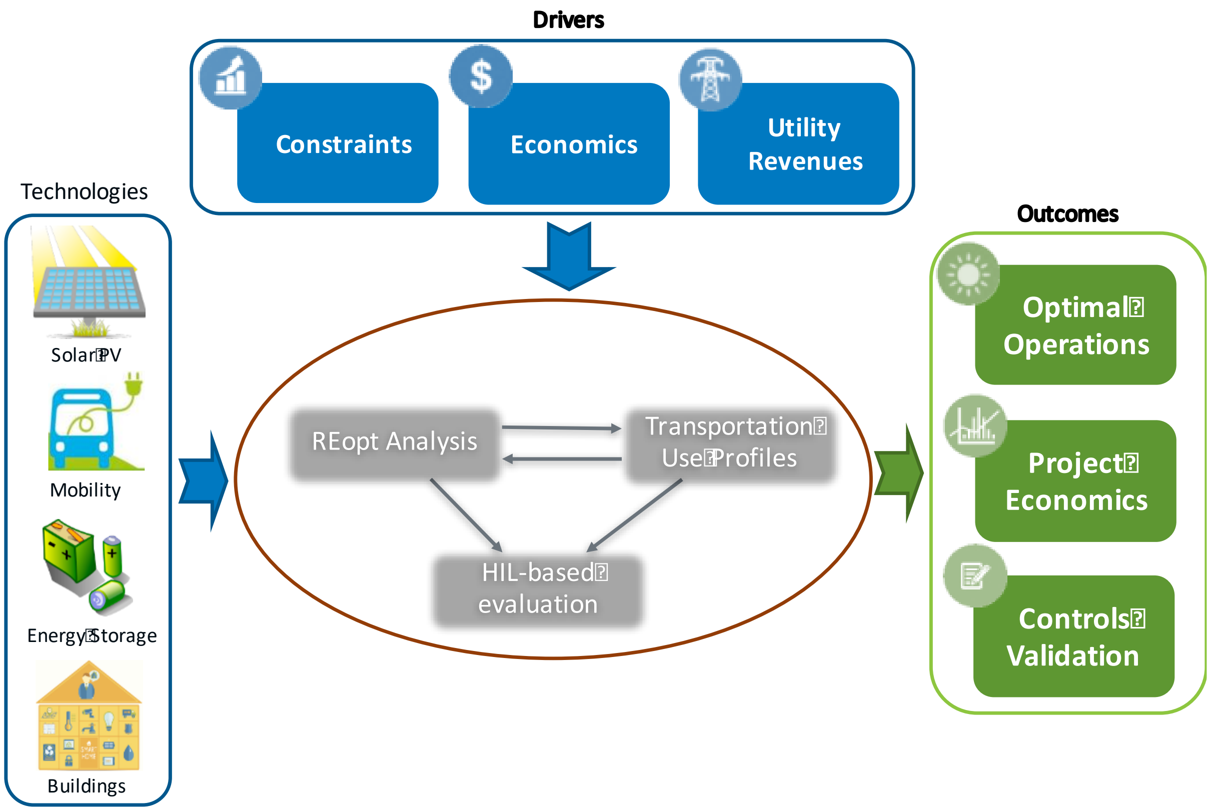


**Figure 1: A replicable platform for evaluating EV fleet management and quantifying benefits from grid services**

The project will leverage the opportunity from electrification of transportation fleets to optimize multiple DER technologies at a site. Synergistic site controls will unlock additional value streams for the different stakeholders and accelerate technology adoption. The following are the major scope items that will be covered in this project:

1. Perform REopt analysis for EV fleet grid services for two sites (in two different regions)
2. Develop transportation use profiles and battery load profiles for selected scenarios
3. Hardware in the loop (HIL) evaluation of fleet charge management for the selected scenarios
4. Form a Project Advisory Team to review results

**Task 1: Perform regional REopt analysis to identify opportunities in different markets**

The NREL team will build upon the initial REopt analysis to identify the different grid services and the US regions where those grid services will provide highest benefits. The effort will utilize NREL's Fleet DNA data which includes over 85,000 miles of 1 Hz GPS and J1939 CAN data from 247 school buses operating in real-world service – including two California school districts participating in the CGI V2G school bus program.

**Results**

NREL evaluated opportunities in two different regions: Berkeley, California, and Montvale, New Jersey. These locations were chosen to represent a range of different grid services and market values available in the United States. In Berkeley, we evaluated opportunities for savings through peak load management and demand response. In Montvale, we evaluated peak load management, frequency regulation, and resilience. NREL used the REopt tool (see Figure 2) to evaluate the impacts of integrating the following technologies at a secondary school: 1) electric vehicle school buses; 2) photovoltaics; 3) stationary batteries; and 4) flexible dispatch of chillers with thermal energy storage. We examined the impacts of EV bus charging on a school's life-cycle energy costs, including the potential additional market revenues available in each service territory, under different EV charging methods including unscheduled charging, optimal charging, and vehicle-to-grid capability.

We found that adding electric buses increases electricity consumption, and scheduled charging can avoid some of the electricity bill cost increases that might occur with unscheduled charging. For the markets analyzed, vehicle to grid and market participation can make EV bus charging cost neutral and even generate cost savings on the electric bill. In Berkeley, CA, a school that implemented electric buses would save $412,000 over 25 years through reduced fuel costs and electricity bills. In Montvale, NJ, savings would amount to $326,000 over 25 years. Avoided diesel fuel costs make up approximately two thirds of the savings, while reduced electric utility bills make up about one third of the savings. For additional details, see (Becker, et al. 2019)**.**

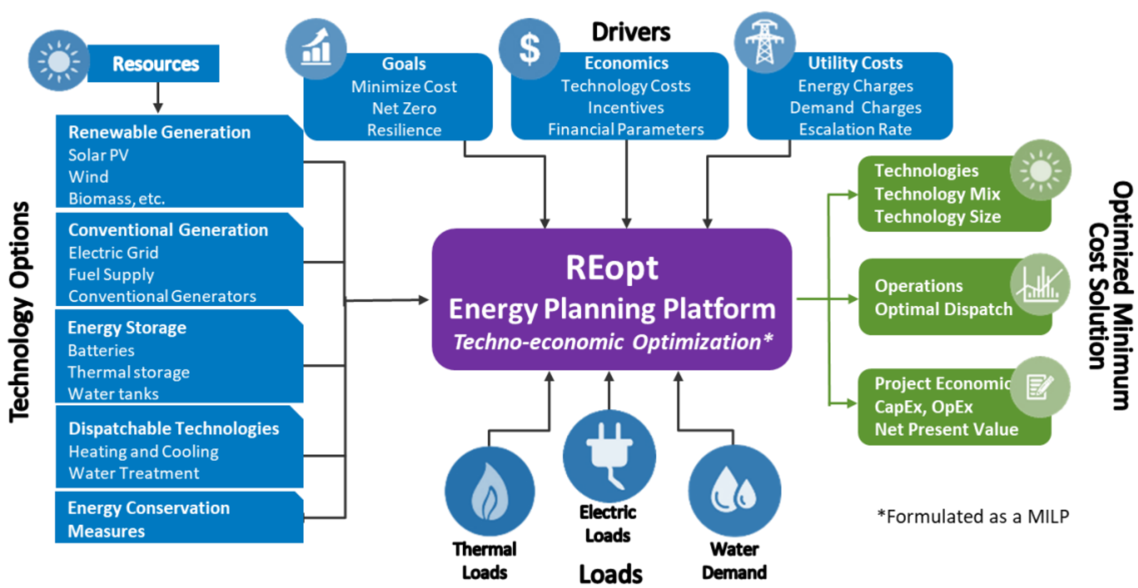


**Figure 2: The REopt model used to evaluate the value of bus electrification in different markets**

**Task 2: Develop transportation use and battery load profiles for selected scenarios**

The NREL team will develop different scenarios in which the electric bus fleet will operate. Factors that influence transportation use and battery load profiles will be identified and representative profiles will be developed for each scenario. Factors include commute distance, gradient, vehicular speed, grid services being performed, etc.

**Results**

The duty cycles of the electric school buses were simulated using an electric school bus model and data logged from school buses used in Torrance, California. Although Torrance, California is geographically dissimilar to New Jersey, this was the best available data, and the school bus driving profiles are representative of a suburban school anywhere in the United States. The GPS coordinates and elevation of each bus were logged every second. From these measures, vehicle speed, acceleration, and road grade were calculated. The vehicle drivetrain model is a variant of NREL's FastSim vehicle simulation tool. Figure 3 shows the vehicle state of charge and bus depot occupancy for one week. For additional details, see (Becker, et al. 2019)**.**

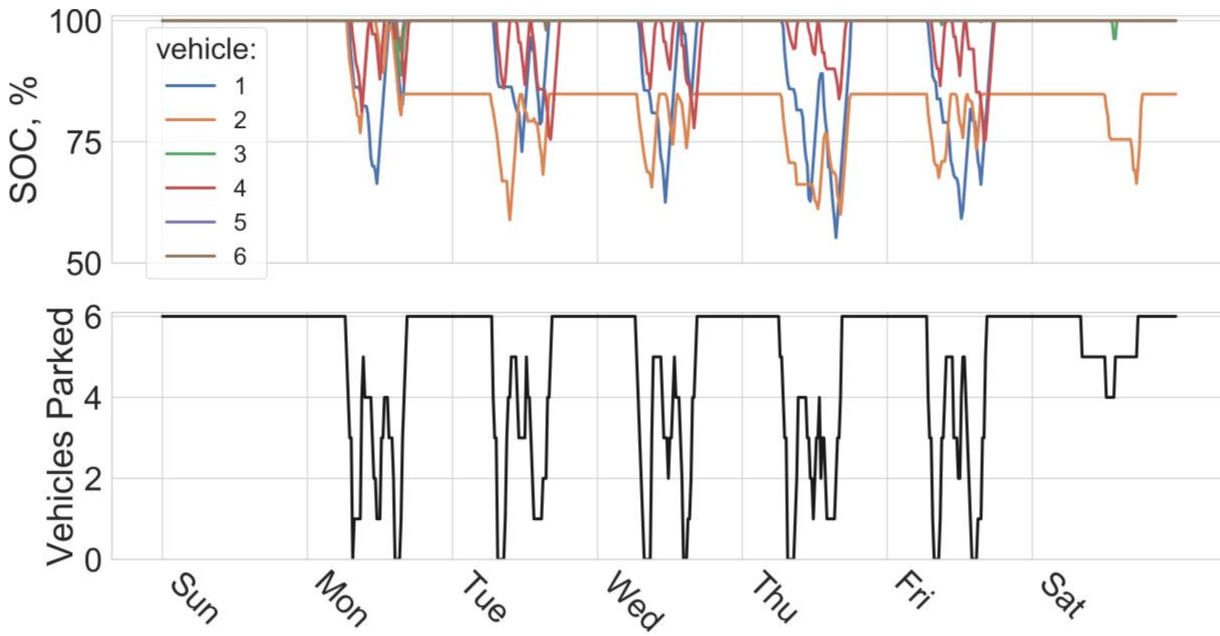


**Figure 3: State of charge and occupancy of bus depot for one week.** (Becker, et al. 2019)

**Task 3: HIL Evaluation of Fleet Charge Management Strategies**

In this task, the fleet charge management control strategies will be evaluated using HIL simulations at NREL's ESIF. Techno-economic analysis will be performed using the results.

**Results**

For the Montvale, New Jersey site evaluated in Task 1, we evaluated fleet management controls strategies using HIL simulations in NREL's ESIF to test more sophisticated control and power/energy management strategies. We configured the Power Xpert Energy Optimizer (PXEO) site controller, which offers primary, secondary, and tertiary levels of control functions. Primary functions represent the SCADA functions for monitoring and control of an asset based on simple rules (such as a state-of- charge (SOC) violation). Secondary functions include more advanced functionalities, such as dispatching asset(s) based on external schedules. Tertiary functions include the ability to account for real-time deviation from forecasts and adjust the planning schedule to optimize the user-defined objectives for cost/performance. We developed a HIL test bed integrated with a commercial site controller and tertiary controllers to minimize the site energy costs.

Results show that integrating site controllers allows an effective and extensible means to integrate advanced power and energy management algorithms. The controls resulted in significant savings in monthly energy bills from demand (peak power) and energy costs. For the small-scale commercial customer, the savings in demand charges and energy amounted to monthly savings of $860 to $4,065. Using V2G strategies can further improve the savings with more efficient energy usage and peak shaving, resulting in an additional $2,200 in savings. It is expected that with a higher penetration of EVs, the energy cost saving opportunity in demand charges will further improve. For more detailed results, see (Jain, et al. IEEE).

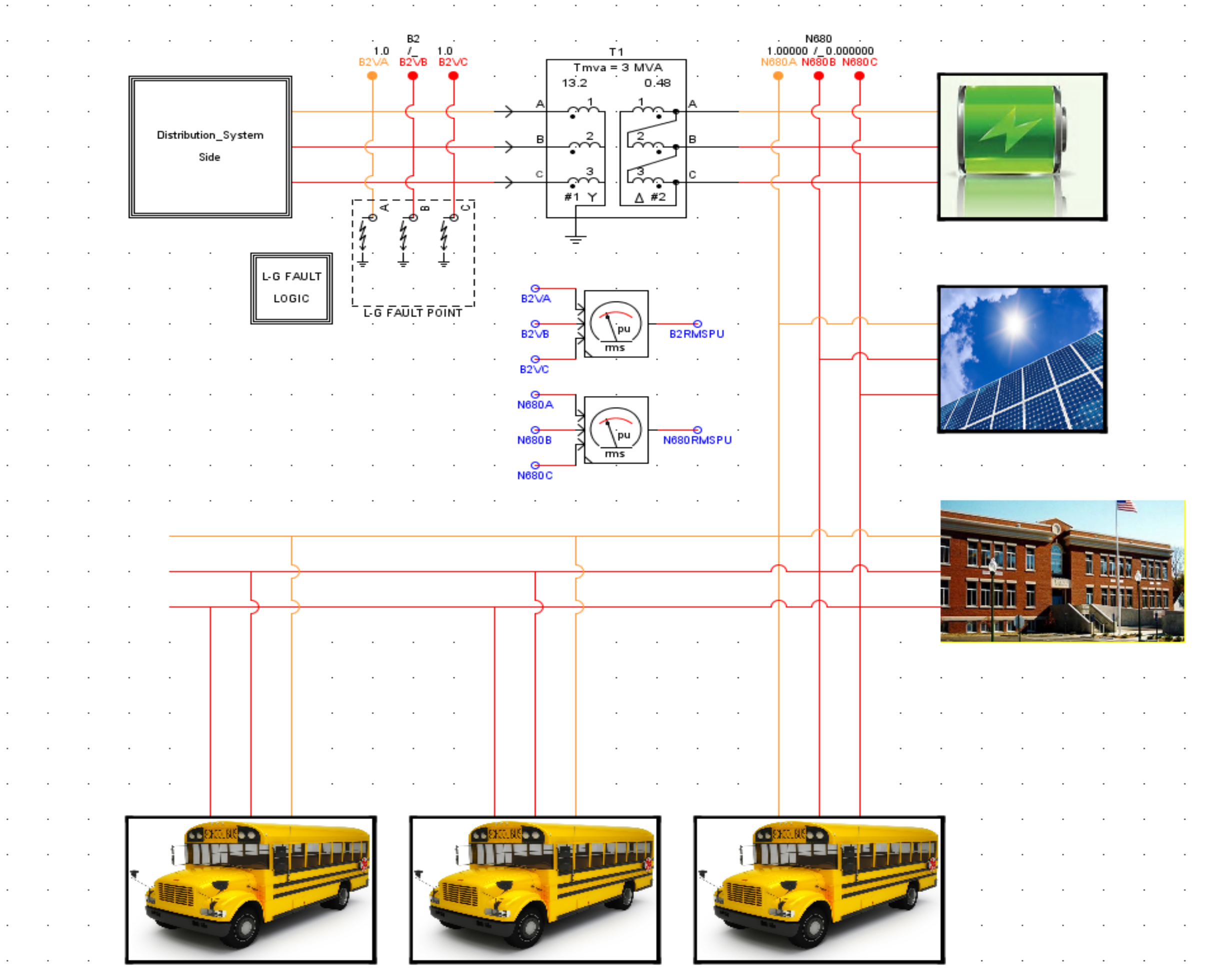


**Figure 4: Overview of the test set up**

## Task 4: Form Project Advisory Group

In this task, project advisors will be identified from stakeholders like fleet owners and utilities, and a project advisory group will be assembled. The purpose of the advisory group is to review the project progress and provide feedback to ensure that the project addresses important challenges.

## Results

The industry advisory board consisted of 30 members from 15 different organizations. This included utilities (SDG&E, HCE, Duke Energy, Xcel Energy, LADWP, NRECA, PECO, ConEdison, and Southern Company), fleet operators (Amazon, Walmart, and UPS), OEMs (Eaton, and Navistar), as well as Electrify America, EPRI, and CalStart. The group was convened twice per year to review project progress and provide feedback on key challenges to address.

## MODIFICATION 1, PROJECT 2

### Task 5: Building Automation Software Review and Planning

In this task, NREL and Eaton will develop a strategy for commercializing NREL's Foresee™ home automation software platform

### Results

NREL made Foresee™ software code available to Eaton and supported extended discussions related to its development and additional work associated with eventual commercialization. NREL and Eaton collaborated to define aspects of Foresee™ which could be adapted easily into Eaton's product line(s) for building automation. NREL and Eaton determined the next steps would involve a follow-on CRADA targeting specific spin-off opportunities, rather than the direct process of road-mapping and piloting an Eaton-commercialized Foresee™ software solution. NREL and Eaton collaborated to develop a work scope for a follow-on CRADA, including the following topics: Building electricity submetering solutions, Software solutions for managing EV charging, Site Solar Forecasting, Residential Building Operations Recommendation Engine, BEMS Audit Tool, Grid Services from Buildings. Figure X describes Foresee™; more information is available (Jin, et al. 2017).


**Figure 5: foresee home automation software platform (Jin, et al. 2017)**

## Conclusion

This research used real-world logged transportation data combined with actual market revenue streams to model the value in integrating DERs and controls with electrification of transportation. We developed a site controller with modular functionality and the ability to integrate with external controllers. Hardware-in-the-loop demonstrates the feasibility and practicality of implementation, and the validation of test results. In the two locations modeled, there is a positive business case for this integration. However, availability of markets for ancillary services is location-dependent and greatly affects the value case. There are significant monetary and resiliency benefits when all DER technologies are optimized as a system. Economics of fleet electrification are less favorable when performed in silos. Given the advancement in battery technologies, the impact of smart charging and V2G services has minimal impact on battery life.

Future work may include engaging with transportation authorities for public bus fleet electrification; engaging with other partners for HD truck electrification; engaging with FCTO to consider hydrogen vehicles for long haul; and managing an XFC site with an electrolyzer and a fuel cell in addition to other DERs.

## Subject Inventions Listing:

None

## ROI:

None

## References:


Becker, W., E. Miller, P. Mishra, R. Jain, D. Olis, and X. Li. 2019. "Cost Reduction of School Bus Fleet Electrification with Optimized Charging and Distributed Energy Resources." *North American Power Symposium.* Wichita, Kasas: IEEE. 1-6. doi:10.1109/NAPS46351.2019.9000330.

Jain, R., S. Veda, W. Becker, S. Ketring, and D. Ganger. IEEE. "Application of Site Controllers for Electrification of Commercial Fleet Vehicles." *2020 IEEE/PES Transmission and Distribution Conference and Exposition (T&D).* Chicago, IL: IEEE. 1-5. doi:10.1109/TD39804.2020.9300038.

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