EVTC™ Electric Vehicle Transportation Center

Semi-annual Program Progress Performance Report for
University Transportation Center

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University of Central Florida

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Electric Vehicle Transportation Center
Submitted by:
University of Central Florida

I. Accomplishments

What are the major goals and objectives of the program?

The Electric Vehicle Transportation Center (EVTC) supports the U.S. Department of Transportation's strategic goal of planning for near-term integration of alternative fuel vehicles as a means to build a sustainable transportation system. The project objectives are to evaluate technologies, standards, planning and policies to ensure seamless integration of electric vehicles (EVs) into a complex transportation network and electricity grid. The EVTC bridges the gap between deployment of electric vehicles and the traditional transportation system.

What was accomplished under these goals?

Summary: This reporting period the EVTC authored 20 publications and 16 presentations, attended 4 workshops and conferences, held or participated in 17 STEM events, and published 2 newsletters. Researchers in Hawaii have applied for a provisional patent (Project #9).

In the research area, a life-cycle assessment was completed for workplace charging stations (Project #3), models were developed for assessing battery energy storage used for demand limiting applications and for siting public EV charging stations (Project #8), Li-Ion battery cell performance measurements continued (Project #9), and a 30 kVA bi-directional V2G power supply was installed in the EV lab (Project #15).

Collaborative efforts for the period included engagement with Florida DOT and the University of South Florida on transportation planning to accommodate EVs. In the education and STEM area, six courses were offered, 17 STEM and K-12 education events were held, and 80 attendees and 14 sponsors are currently registered and/or supporting the EVTC's second EV Transportation & Technology Summit in October 2016.

Research and Development Accomplishments

The EVTC R&D agenda identified 22 projects and respective teams have been conducting detailed research. A summary of results for each project are presented in the following sections. Referral for additional details of each project is made to the EVTC website and previous PPPRs. The project results include 20 new publications. These publications are presented by reference numbers in the R&D reporting section with the formal citations, and are listed in the results dissemination section on pages 18-19.

1. Implications of Electric Vehicle Penetration on Federal and State Highway Revenues

Objective: *Research the impact that increased use of electric vehicles will have on federal and state highway revenue sources. This work will identify existing laws and policies that govern highway, gas, and vehicle taxes and fees imposed on vehicles and summarize current trends and policy recommendations that may influence both the growth of the electric vehicle market and impact highway revenues.*

Accomplishments: The passage and signing by President Obama of the FAST Act completed road tax funding for five years. A project report on the influence of EV sales on road tax was reported in PPPR #5. This report completed the project.

2. Identify and Analyze Policies that Impact the Acceleration of Electric Vehicle Adoption

Objective: *Examine state and national regulatory policies to determine their impact on the long term adoption of electric vehicles. The work will include discussion with Florida utility companies and with* *existing electric vehicle stakeholder groups. New policies and or regulations will be developed and suggested to the appropriate authorities. This project will also include Hawaii and Alabama.*

Accomplishments: The project continues to monitor developments in EV policy. Project has reviewed activities done by U. S. DOE Clean Cities Alternative Fuel Data Center and Drive Electric Florida. Work is continuing to identify legislation and future market and policy opportunities.

3. Electric Vehicle Charging Technologies Analysis and Standards

Objective: *Assess current and emerging technologies, codes and standards associated with Electric Vehicle Service Equipment (EVSE), Electric Vehicles (EVs) and the related infrastructure. The work will recommend policies and best practices to advance both vehicle and EVSE deployment. Collect and analyze 50kW DC fast charger usage data to evaluate electrical power impact.*

Accomplishments: The project has produced a report that examines the life-cycle costs associated with the charging of electric vehicles and the impact that plug-in electric vehicle (PEV) charging may have on commercial building electricity cost[1]. Through a life-cycle assessment of typical EVSE equipment, including first cost and maintenance and operating costs, it was found that AC Level 1 or 2 workplace charging can be similar to or lower in cost than charging at home. The cost to charge a PEV at home using an AC Level 1 charging station is $1.79 per charging session while charging at work would cost $1.53 if utility demand charges were not part of the electric bill or $1.79 if demand charges were included. Charging the PEV at higher power levels (e.g. AC Level 2 or DC Level 2) can result in much higher costs when charging stations are used less than 3 times per day.

4. Transportation Planning for Electric Vehicle and Associated Infrastructure

Objective: *Identify and examine transportation infrastructure planning models and related policy issues associated with the deployment of Electric Vehicles (EVs). Recommendations for planning and policy actions to accommodate EVs and EVSE infrastructure will be provided and an assessment of the how EVSE infrastructure planning will enhance EV acceptance will be produced. Infrastructure deployment feasibility models will also be developed.*

Accomplishments: The project focus has been to identify existing EV transportation planning models, to develop research partnerships and to evaluate planning activities occurring in Florida and the U.S. Current models do not provide considerations for deployment of EVs or other alternatively fueled vehicles. The two activities of the period have been the submitting of a proposal to Florida DOT and the planning for the EVTC Summit. The FL DOT proposal on Integrating Electric Vehicles into Local and Regional Planning is in continuing negotiation and should begin before year-end. The goals of this research project are to identify national best practices for supporting electric vehicles through land use and transportation planning, and to provide guidelines for FL DOT and other transportation planners to support EV integration efforts.

The second EVTC's *EV Transportation & Technology Summit* will be a four day event for key EV stakeholders held on October 17-20, 2016. There are currently 80 attendees and 14 sponsors registered for the event. The Summit will provide an update on the current state of EV deployment, technology and planning. The Summit will be proceeded by an EV and Battery Technology Workshop and an EV Powertrain, V2G Technology and EV Case Study Workshop. The Summit and workshops provide an opportunity for transportation planners, electric utility service providers, students and stakeholders to learn about EV technologies, issues and policies. Summit details may be found at the Summit website, http://www.evsummit.org/.

Figure 1. EVTC's EV Transportation & Technology Summit

5. Prediction of Electric Vehicle Penetration

Objective: Identify past and present trends in electric vehicle sales to establish a baseline of electric vehicle penetration and to predict electric vehicle sales and sales characteristics within the U.S. Compare EV sales by states and evaluate the types of barriers to EV usage and the actions or incentives to overcome the barriers.

Accomplishments: A report was published with the EV sales values for 2015 and barriers[2]. The results show that China leads in yearly sales at 214,283 (triple increase over 2014) followed by Western Europe at 184,500 vehicles sold. The U.S. is third at 115,262 followed by Japan at 46,339 vehicles. These four countries comprise 95% of the global sales market. The world total of EV sales for 2015 is estimated to be 565,668 up from 315,519 in 2014. The data also shows that the overall world growth is 79% and that Western Europe is now ahead of the U.S. in total cumulative vehicles. Within the U.S., the PEV sales results for 2015 show that 115,262 vehicles were sold as compared to 118,882 vehicles in 2014 which is lower by -3 %. However, sales for the first 6 months of 2016 are 19% greater than the sales for the same period in 2015. On a state basis, California is the largest market with about 55% of the sales. The total cumulative number of EVs sold in the U.S. over the six year lifetime is now at more than 400,000 vehicles. The report also evaluated the types of barriers to EV usage and the actions to overcome. The barriers are costs, range, availability of charging stations, charging time, battery life and infrastructure, standards and permitting. Incentives and technical progress results are presented for overcoming each of the barriers.

6. Electric Vehicle Life Cycle Cost Analysis

Objective: *Compare total life cycle costs of electric vehicles, plug-in hybrid electric vehicles, hybrid electric vehicles, and compare with internal combustion engine vehicles. The analysis will consider both capital and operating costs in order to present an accurate assessment of lifetime ownership costs. The analysis will include vehicle charging scenarios of photovoltaic (solar electric) powered charging and workplace charging.*

Accomplishments: This project compared total life cycle costs (LCC) of battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV), hybrid electric vehicles (HEV), to vehicles with internal combustion engines (ICE). The results have been previously presented as a paper and as a computer program of life-cycle costs (LCC). Project 6 is considered complete.

7. Assess Existing Software and Databases

Objective: *Evaluate the feasibility of using the existing software and data bases as platforms for analyzing the attributes of electric vehicles within present and future transportation infrastructure projects and models.*

Accomplishments: This project had no activity and was reported on and completed in previous PPPRs.

8. Battery Technologies for Mass Deployment of Electric Vehicles

Objective: *Assess current and emerging battery technologies and the requirements for their commercialization; align with DOE targets for future EV batteries. Focus will be placed on battery technologies, charging cycles, lifetimes, safety, codes and standards, and economics.*

Accomplishments: As plug-in electric vehicles become more widespread, there will be opportunities to integrate the vehicles into a building's energy management system. These vehicle-to-grid (V2G) applications will enable more efficient operation of the building while reducing electricity demand charges. However, V2G will also introduce novel demand cycles on the battery that could be in excess to the manufacturer's design specifications. Understanding how these new applications impact battery lifetime is critical in the future acceptance of V2G technologies. During this period, a Matlab model was developed that optimized the number of vehicles operating in a V2G configuration at a building, together with solar electric PV arrays and stationary storage. The impact of the vehicles' charging on the building demand profile can also be ascertained. By optimizing the vehicles for V2G applications, future demand profiles may be defined which will more accurately assess the viability of battery technologies in meeting the buildings' energy needs. Using the FSEC building monthly energy demand as a case study, nearly 10% savings in electricity costs may be achieved by using a system of PV, V2G and stationary batteries. Surprisingly, the battery size required is less than 1% of the daily energy draw of FSEC's building. This indicates that substantial savings may be achieved through small energy storage options.

In addition to the V2G efforts, a model was developed to identify the density and locations of new charging station locations. This model is useful for city planners to identify future locations where charging stations would be employed, as well as to determine how many charging stations should be located at each site. The model approach is to minimize the costs associated with charging station infrastructure, driving distances, and wait times for a given population of electric vehicles. Orlando, FL was used as a case study, and it was determined that the optimal number of charging stations is around 128. Currently, the city has 67 sites suggesting that more stations would be needed to meet future needs. Based on the current usage patterns, the model identified workplace and transportation hubs as the most likely locations for future Orlando charger installations.

9. Electric Vehicle Battery Durability and Reliability under Electric Utility Grid Operations

Objective: *Determine the impact of electric vehicle use on battery life including charging cycles and vehicle-to-grid (V2G) applications. The work will identify conditions that improve battery performance and durability. Focus will be placed on providing battery data for system engineering, grid modeling and cost-benefit analysis.*

Accomplishments: Battery degradation is extremely important to EV technologies and is a function of several factors -- electrode chemistries, operating temperatures, and usage profiles (i.e. vehicle-only vs. vehicle-to-grid applications). The goal of this research was to assess such impact. Laboratory testing of commercial "18650" Li-ion cells was conducted in Hawaii Natural Energy Institute's sustainable energy laboratory[3]. The battery test plan used two separate experiments: a cycling experiment to assess the impact of both V2G and G2V strategies and calendar aging experiments to assess impacts of temperature and SOC.

The results to date have shown a measurable impact of V2G, temperature and SOC on the battery capacity loss and indicate that V2G strategies seem to double the capacity loss when performed twice daily[4,5]. Results also show that under current testing conditions the batteries would only last 36 months before losing 20% of their capacity compared to at least 72 months for cells not participating in V2G. To verify this result, detailed analysis is being performed to identify whether or not the accelerated degradation observed for the V2G strategy is the same as the normal degradation. Preliminary results indicate that the degradation differs and that V2G usage not only degrades the cell faster but also impacts the negative electrode more intensely. This result could have significant impact on the remaining battery life and further reduce the 36 month estimated life and/or prohibit second use for these batteries. The results are yet to be confirmed by further testing and by modeling. High temperature and high SOC also showed to be 3 to 4 times more detrimental effect than lower temperatures and SOC levels. Delayed EV charging (G2V) was found to have no impact so far.

Dr. Matthieu Dubarry and a team of researchers at UH have applied for a provisional patent entitled, "Apparatus & Method for Estimating the State of Health of a Battery via Updating the OCV and SOC relationship." The patent addresses issues with accurately determining the SOC as batteries begin to age.

10. Fuel Cell Vehicle Technologies, Infrastructure and Requirements

Objective: *Investigate state-of-the-art fuel cell vehicle technologies, and current infrastructure developments. Conduct comparative study of fuel cell vehicles and battery electric vehicles in terms of technical and economic viability.*

Accomplishments: The hydrogen fuel cell electric vehicle (FCEV) moved from concept demonstration to commercialization in 2015. This project investigated the technical and commercial aspects of these technologies and the hydrogen fueling infrastructure that are required for the fuel cell powertrain configurations. Results were published in three EVTC technical reports. The project's current effort is focused on analyzing hydrogen production and previously reported hydrogen storage, economic analysis, and life-cycle analysis (LCA). For the LCA over 50 reports have been reviewed with the results being consolidated into a review paper. The goal is to predict how FCEV may affect the U.S. transportation in the near-term and mid-term future, and to identify research gaps and future opportunities.

Additionally, a Hydrogen at Scale (H2@Scale) concept has been proposed by the National Renewable Energy Laboratory (NREL) and has gained attention in the hydrogen community. EVTC researchers have been actively involved in contributing to this concept by including the FCEVs into the hydrogen ecosystem. The research effort currently focuses on new fuel cell battery hybrid powertrains and their impact on the future requirements for hydrogen fueling infrastructures. The new powertrain is being studied using ADVISOR, a vehicle simulator developed by NREL.

11. Electric Vehicle Grid Experiments and Analysis

Objective: *Provide data from experimental vehicle-to-grid laboratory simulations. The results of the experimental data will be used in the EVTC techno-economic simulation project.*

Accomplishments: The project has developed a low-cost building energy management system (EMS) that includes workplace chargers and allows commercial building operators to minimize electric utility bills for workplace charging. Eight months of utility power data have been evaluated. This data shows that workplace chargers intermittently impose a monthly demand charge on the facility electric utility bill. Further analysis has determined that these costs can be minimized or eliminated with a predictive control algorithm. A report describing the results is under review. The algorithms described will be implemented while further data is collected for verification.

In the EVTC laboratory, a Princeton Power System CA-30 bi-directional EV charger has been installed. Communications coupling the Princeton unit with the existing building EMS system is now under development. This system will be used to control Level 2 EV workplace and public charging stations. The VOLTTRON™ communications platform and other V2G software will be used to further develop EMS control algorithms. Initial experiments will use EV batteries to shift building peak demand, offset DC fast charger operation, and develop third party (i.e., utility companies) access protocols.

12. Electric Vehicle Interaction at the Electrical Circuit Level

Objective: *Investigate the effect of electric vehicle adoption on the circuit level utility distribution grid for both residential and commercial applications by determining the impact of electric vehicle charging and discharging to the grid.*

Accomplishments: This project has studied the impacts of electric vehicles (EVs) on the electricity distribution grid. A transient time domain model of a sub-circuit service area with PV power has been developed. The model uses EV charging as a means of mitigating transient over-voltages (TOVs) in various scenarios[6]. A developed and novel methodology for early detection of TOVs has shown that charging stations combined with the connected grid load of the EV can be used to eliminate over-voltage peaks and improve the response time and reliability of inverter-based islanding detection, thus, increasing grid reliability.

13. Optimal Charging Scheduler for Electric Vehicles on the Florida Turnpike

Objective: *Develop the methodology for analyzing the roadway traffic patterns and expected penetration and timing of electric vehicles (EVs) on the Florida Turnpike. The work will determine the requirements for electric vehicle supply equipment at turnpike plazas, the options for equipment siting and the economics.*

Accomplishments: Previously presented results developed a systematic methodology and analytical model for analyzing expected penetration of electric vehicles (EVs) and their impacts on the overall transportation infrastructure. The Florida Turnpike network has been used as a test system for this network project using real-world data that were collected and compiled from the Regional Integrated Transportation Information System (RITIS) database (Project 7). Computer simulations were conducted for 24-hour Florida Turnpike roadway traffic data and the currently installed electric vehicle charging equipment data at the turnpike plazas. The charging equipment utilization and electric vehicle waiting time are compared for different EVs penetration rates and charging strategies. The results demonstrated that the proposed strategy results in a uniform utilization of the charging equipment at the service stations. The Turnpike has installed 6 Tesla superchargers each at 2 plazas which are used about twice per day on average (i.e., over 600 sessions per month). Two peer-refereed papers on the modeling have been published. Three conference and journal articles on scheduling EVs on the Turnpike and on micro-grid operation have been published [7,8,9,10], and an additional conference paper is being accepted [11]. Thus, Project 13 will be considered completed with the pending publication of these research papers.

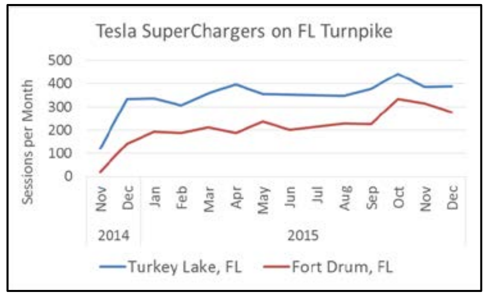

Figure 2. FL Turnpike EVSE use

14. Electric Vehicle Bus Systems

Objective: *Investigate the implementation strategy and the operation of an electric bus fleet and compare the operational data with a baseline diesel bus fleet. Model an electric public bus transportation system in a selected city.*

Accomplishments: Pure electric buses (EBs) present an alternative in the transit bus arena and are being manufactured and sold by several US companies. In this project, Tallahassee StarMetro's five EB fleet was used as a case study. Route distance and timing, charging durations and scheduling, and other operational characteristics of the EB fleet were compared with the StarMetro diesel bus fleet.

The electrical demand charge was shown to contribute on average 74% of the total electricity bill. This result was due to EBs' fast charging at high power may present a major challenge with EB adoption. Demand charges are an additional utility fee based on the peak power used during a given billing cycle, normally one month. Due to the high demand charges, a research effort was undertaken to find means to reduce these charges.

An energy consumption model was developed to simulate the fuel economy of the EBs for any given driving cycle. The model was then used to study the impact of routes and EB charging strategies on demand charges. An objective function was created to search for the optimal charging strategy that results in minimizing demand charges. A case study was conducted on the Tallahassee EB fleet which showed the optimized charging strategy results in a 41% savings for a five EB fleet over 12 years operational period. The EB charging strategy can be easily adopted by transit agencies without added hardware costs.

Other project work examined and evaluated how many EBs can be accommodated by one fast charger in a given route and ridership, and how fleet sizes affect demand charges. For lithium titanate based EB systems, fast charging stations are an essential and expensive component. The capital and installation cost of the fast charger in Tallahassee was $1.165 million. As a result, early adopters of EBs will likely start with only one fast charger. These results showed that, in the case of StarMetro's current route, 13 EBs is the theoretical maximum that one fast charger can accommodate. The average demand charge costs per bus generally decrease with increased fleet size.

The details of above mentioned studies are presented in a peer-reviewed paper titled "Numerical Analysis of Electric Bus Fast Charging Strategies for Demand Charge Reduction". The paper was accepted by the Transportation Research Part A: Policy and Practice on Sep. 12, 2016 and is currently in press[12].

15. Electric Vehicle and Wireless Charging Laboratory

Figure 3. PPS CA-30

Objective: *Furnish, equip and operate an EV and Wireless Charging Laboratory within the FSEC laboratory facilities. This facility will function as a laboratory where EV vehicles are charged and discharged through a computer assisted communication network and where wireless chargers are evaluated.*

Accomplishments: A Princeton Power System CA-30 bi-directional charger has been installed. The unit can charge and discharge CHAdeMO supported PEV traction batteries. The unit is currently being programmed for automated communication. Efficiency experiments continued in the wireless lab.

16. Electric Vehicle Fleet Implications and Analysis

Objective: *Evaluate the implementation and effectiveness of electrical vehicles used in fleet operations. The project will evaluate present usage through case studies. The results will be used to evaluate other vehicle applications and to determine how EV fleet adoptions could impact overall rates of market penetration and what are the programs or incentives that could encourage EV fleets.*

Accomplishments: According to the U.S. DOT, there are more that 11 million fleet cars and trucks in the U.S. Fleet vehicles regularly cover predictable routes and often return to central depots at night, thus, having a centralized recharging location makes them excellent candidates for conversion to electric. PEVs are particularly attractive for light-duty fleet use because of their reduced fueling expense and lower overall maintenance cost. Significant momentum is developing for the conversion of the nation's federal governmental vehicle fleets to electric drive. Project activities include the continued review of case studies and policies to evaluate the effectiveness of fleet electrification. A report on the implementation and effectiveness of electric vehicles used in fleet operations has been completed and is under review. The report reviews regulatory, operational and expense considerations and provides a review of current use and applications. Classes of vehicles from Class 1 motorcycles to Class 8 semi-trucks are covered and show a broad spectrum of current usage. Case studies include the use of electric motorcycles by police departments, EVs in ride-sharing and as taxis and mass transit electric buses. The report also identifies the programs, incentives and legislative mandates that encourage the expansion of EV fleet use, and how these programs may increase overall rates of market penetration and encourage new applications.

17. Electric Vehicle Energy Impacts

Objective: *Evaluate the impacts of electric vehicles and associated renewable power generation on reduction of petroleum imports to Hawaii. The analysis will concentrate on the Island of Oahu and will include the effects of number of vehicles, charging strategies, renewable energy penetration levels and green-house gas reductions.*

Figure 4. Hawaii Charging Stations (photo K. McKenzie)

Accomplishments: Analysis of EV integration in Hawaii has been built on high fidelity grid modeling of future Oahu renewable energy scenarios. As Hawaii moves toward 100% renewable power by 2045, EVs become increasingly important in helping to balance intermittent power generation and load. The model results quantify net petroleum and GHG emissions savings. As determine by the project's analysis, EV fuel use on Oahu has improved from 32 miles per gallon gasoline equivalent (MPGe) in 2012 to approximately 36 MPGe today. In future scenarios with 36% renewable electricity generation and 20% of the vehicles replaced with EVs, EVs would achieve 44 MPGe. EVs also offer a significant amount of battery energy storage that could contribute to balancing the power grid as more intermittent renewables are added and less power is required from fossil fuels. For Hawaii, these changes to both ground transportation and electricity would have a significant effect on reducing petroleum imports to the nation's most petroleum dependent state.

Recent modeling by HNEI and GE of future scenarios with 50% wind and solar energy show power curtailment of 12% to 27% depending on the mix of resources. In high solar scenarios (over 40%), approximately 90% of any additional solar energy would be curtailed[13]. Additional modeling and analysis efforts are being conducted to increase understanding of EVs effect in balancing renewable energy integration on the power grid. This work is directly applicable to isolated grids, micro-grids and large grids at the distribution or circuit level. Another phase of the EV analysis will model wind and solar energy up to 70% penetration levels to determine the significance of EVs in balancing these intermittent power sources. Additionally, EV energy charging and storage will be analyzed as a means of improving power quality and stability while increasing renewables.

18. Socio-economic Implications of Large-scale Electric Vehicle Systems

Objective: *Develop models to evaluate the socio-economic implications of a large-scale electrified transportation sector. Model factors include effects of vehicle and infrastructure safety requirements, standardization of vehicle components for safety and charging, electric vehicle supply and after-market economies, displacement of petroleum fuels and impacts of sustainable development (social, environmental and economic).*

Accomplishments: The research team focused on four research areas as follows:

V2G Technology: Applications of Vehicle to Grid (V2G) technology in sustainable transportation was investigated. V2G technologies use idle electric vehicle battery power as a grid storage tool to mitigate fluctuations from renewable electric power sources and to help supply backup power in the event of an emergency. The results indicate that this system can lower the cost of the required grid electricity and provide for a net zero energy building[14]. The results also show that grid electricity consumption for this case can reduce the power used by a conventional building by up to 68%.

Class 8 Heavy-duty Trucks: The objective of this research was to use a hybrid life-cycle assessment method to analyze and compare alternative fuel-powered Class 8 heavy-duty trucks (HDTs) with conventional trucks. The results show that battery electric HDTs outperform all other types of trucks overall, despite their incremental costs and electricity generation-related emissions[15]. Furthermore, if such a truck were to run on electricity generated in the Northeast Power Coordinating Council (NPCC) region, fuel-consumption related GHGs emissions from BE HDTs could decrease by as much as 63 percent. If electricity is generated from renewable energy sources, the use of BE trucks would significantly improve the life-cycle performance of the trucks as well as ambient air quality.

Delivery Trucks: Due to frequent stop-and-go operation and long idling periods when driving in congested urban areas, the electrification of commercial delivery trucks offer a savings opportunity. In this research, environmental impacts of various alternative fueled delivery trucks including battery electric, diesel, diesel-electric hybrid, and compressed natural gas trucks were analyzed. The analytical results show that although the battery electric delivery trucks have zero tailpipe emission, electric trucks are not expected to have lower environmental impacts compared to other alternatives. The adoption of alternative fuel trucks can mitigate the environmental impacts, however, the first cost of these trucks is higher than those of traditional diesel trucks. An economic input–output based hybrid life cycle assessment was performed in conjunction with Multi-Objective Linear Programming to evaluate various delivery truck fleet combinations and to provide a comprehensive analysis of fleet performance. The results indicate that when fuel economy is high and annual mileage is low, current diesel trucks are able to fulfill the requirement in both cases with reasonably low costs. Conversely, in scenarios with low fuel economy and high utilization levels, hybrid vehicles are preferred.

EV Uncertainties: In this research, a novel method, uncertainty-embedded dynamic life cycle sustainability assessment framework, was developed to address both methodological challenges and uncertainties in transportation sustainability research. The approach provides a more comprehensive, system-based sustainability assessment framework by capturing the dynamic relations among environmental, social, and economic impacts within the U.S. transportation system as a whole. Although impacts of electric vehicles have the largest uncertainty, they are expected (90% confidence) to be the best alternative in long-term for reducing human health impacts and air pollution.

19. Economic Impacts of Electric Vehicle Adoption

Objective: Examine the predicted levels of electric vehicle adoption to analyze the opportunity of using EVs as a grid stabilization tool for Hawaii, including GHG emissions impacts. Assess factors that affect EVs adoption, including regulatory mechanisms.

Accomplishments: This project examined future predicted levels of EV adoption to determine the level of opportunity of EV's as a grid stabilization tool. Researchers collected Hawaii data on vehicle adoption rates and practices as applied to Hawaii-specific vehicle ownership. Three reports on EV penetration, EV cost comparisons and GHG emissions have been completed and published. The first report evaluated EV penetration rates and estimated there will be 140,000 EVs on the road in Hawaii by the year 2040. To complement the results of the EV-adoption scenarios, EV lifecycle ownership costs were analyzed in the second report. This report also assessed the impact of the federal tax credit for EVs and of the benefits of household solar photovoltaic systems coupled with proposed time-of-use electricity rates for EV owners. The third report estimated GHG emissions of EVs in Hawaii to include comparisons with similar ICE vehicles[16]. In terms of GHG emissions, EVs offer an improvement over ICEs. However, the model that looks at GHG emissions by county shows that HEVs outperform EVs on Oahu while EVs outperform HEVs on Hawaii Island because of the high level of geothermal electricity. This research report completes this project although a recent successful dissertation may provide amended project results.

20. Techno-economic Analyses of Large-scale Electric Vehicle Systems

Objective: *Develop a computer model to evaluate the techno-economic implications of a large-scale electrified transportation sector. The model factors include developing a network of electric vehicles that interact with the electric grid, the infrastructure for electric vehicle charging, integrating the transportation and power systems into the urban setting, studying the impact of distributed energy storage and determining the economic impact of increased renewable energy and EVs on the grid.*

Accomplishments: This project developed computer models to evaluate the techno economic implications of a large-scale electrified transportation sector. The model factors include developing and interacting with a network of EVs and the electric grid, the infrastructure for EV charging, integrating the transportation and power systems into the urban setting, studying the impact of distributed energy storage and determining the economic impact of increased renewable energy and EVs on the electricity grid[17].

The current research focuses upon several innovative aspects of vehicle-to-grid (V2G) charging and grid feedback. Results are presented in the publishing of four papers[17,18,19,20]. Energy storage and reactive power supplied by EVs through V2G operation can be coordinated to provide voltage support, thus reducing the need of grid reinforcement and active power curtailment and in turn improving EV charging capacity of the overall system. An optimization and control framework is needed to manage energy storage while using the remaining capacity of V2G to generate reactive power and cooperatively perform voltage control. The resilience analyses of power grid with a high level of renewable and EV penetration has been investigated. To present this result, a resiliency index was proposed that will capture the total loads which cannot be supplied under line removal due to extreme weather conditions. Using this index, a control strategy based on line switching is proposed to minimize the total load shedding and to guarantee the power delivery to critical loads due to line outages. This project and its V2G results have a very broad scope and implications.

21. Effect of Electric Vehicles on Power System Expansion and Operation

Objective: *Examine the effects of electric vehicles on electric power systems and their operation. This work includes using an existing Hawaii developed model that will be validated against a large scale* *utility model. The work will evaluate the benefits of optimally-timed EV charging, the requirements and costs of electric grid infrastructure to serve different types of vehicle fleets, and the effects of battery duty cycles used in the vehicle and in vehicle-to-grid applications.*

Accomplishments: This project has setup a version of the SWITCH power system model using Hawaii data. The SWITCH model has been used to provide guidance to Hawaii policymakers as they make plans to meet the state's new 100% renewable electricity target by 2045. Numerous additional capabilities have been added to SWITCH that include spinning reserves; part-load heat rates; fuel markets; battery storage; modeling of arbitrary, and high-complexity demand functions. Other developments have included novel techniques to represent the charging requirements and flexibility of the EV fleet, based on first principles and nationally representative transportation surveys. Additional techniques have been developed to integrate a variety of load and energy profiles efficiently into power system production cost models and capacity expansion models. This project is now complete with report and its results published on the EVTC website[21].

22. Automated and Connected Vehicle Implications and Analysis

Objective: *This project will evaluate the usage and implementation of automated and connected vehicles (AV/CV). The project evaluation will be done through case studies with the results being applied to determine appropriate vehicle applications and how EVs will participate in this new transportation future.*

Accomplishments: Automated and connected vehicles (ACV) can significantly reduce crashes, energy consumption, pollution and the costs of congestion. This technology assessment project evaluated ACV technologies, actions, laws and policies that are now in place or proposed and assessed future ACV usage. The assessment also evaluates the highest level of automated vehicles called autonomous or self-driving vehicles. In September 2016, the U.S. Department of Transportation (USDOT) issued its policy for automated vehicles. The first state to authorize the operation of autonomous vehicles was in 2011, and, since then, eight states (California, Florida, Louisiana, Michigan, Nevada, North Dakota, Tennessee and Utah) and Washington D.C. have passed legislation related to autonomous vehicles. There are pending legislative actions in 10 additional states. The project also evaluated how electric vehicles (EVs) will participate in the future ACV transportation system. The future dollar value is huge with multi-billion dollar investments being made by auto manufacturers, ride sharing companies and technological innovators all looking to establish their positions. EVs will play a major role in this new future due to regulatory reasons (gas mileage and no urban emissions) and engineering reasons (fewer moving parts, reduced maintenance, and vehicles that are configured to drive, steer and brake by wire).

External Collaboration Accomplishments

Key collaborations are:

1. Drive Electric Florida - On-going collaboration with Florida's largest EV stakeholder organization. Current emphasis is on Workplace Charging. (Project 2)
2. Clean Cities - On-going collaboration on a variety of projects and programs to support EV adoption (Project 2)
3. National Fire Protection Association - EVTC in coordination with NFPA has developed training on electric vehicles as well as other alternative fuel vehicles for First Responders (Project 2).
4. Rocky Randels, City of Cape Canaveral, Florida. Consultation on installation of DC Fast Charge for new city hall. (Project 3)
5. University of South Florida, Center for Urban Transportation Research (CUTR)—Collaboration to develop recommendations, policies and guidelines for EVs in the formal transportation and land use planning process. Project proposal submitted to FDOT Research Center, expect project to begin in December, 2016. (Project 4)

6. City of Orlando, FL - Several EVTC and UCF staff members engaged in extensive collaboration with city administrators on their application submittal for the U.S. Department of Transportation's "Smart Cities Challenge" grant and present Orlando activities. Helped prepare documents and met with Charles Ramdatt, Chris Castro, and David Dunn. (Project 4)
7. Hua Jin, Developing a platform to simulate the electric grid and communication, Powersim Inc., (Project 12*)*
8. Noriyasu Matsuno, experiment on hardware platform for controlling the inverters (EV chargers), My Way Plus Inc., (Project 12*)*
9. Mark Lee, Developing smart gateway and smart measurement devices for smart electric vehicle charging stations, SmartGrid Corporation, (Project 12*)*
10. Tony Markel, NREL, Mark Burdge, VIA Motors, Inc., David Dunn, City of Orlando on development of a project on V2G experiments using VIA trucks. (Project 15)
11. GE Energy Management, Energy Consulting - Meeting led by Derek Stenclik, Manager, Power Systems Strategy, monthly steering committee meetings with HNEI, UH, Hawaiian Electric Company and other stakeholders for the HNEI-GE high fidelity grid modeling. (Project 17)
12. Hawaiian Electric Company, planning team and stakeholders - On-going collaboration on modeling methods for the utility's long-term Power Supply Improvement Plan. (Project 17)
13. Blue Planet Foundation, Richard Wallsgrove. Prepared a white paper on "Effect of Electric Vehicles on Design, Operation and Cost of a 100% Renewable Power System", used for "EVs as Sustainable Grid Solution in Hawaii" for briefing at the Rocky Mountain Institute's e-LAB Accelerator Bootcamp for Electricity Innovation at Sundance Mountain Resort, April 24-27, 2016. (Project 21)
14. Florida Department of Transportation - Doug Kettles, appointed to FDOT Florida Automated Vehicles Technology and Infrastructure Working Group in February, first meeting occurred April 2016. (Project 22)
15. Electrathon of Tampa Bay - On-going collaboration with the non-profit organization, which is dedicated to promoting electric vehicle technology through hands-on electric go-cart design, building and endurance racing (STEM activities).
16. Eastern Florida State College - On-going collaboration with the local Brevard County college to promote electric vehicle technology (STEM activities)

Education and Workforce Development Accomplishments

University of Central Florida

The UCF Department of Civil, Environmental, and Construction Engineering (CECE) offered one course that was taught by UTC project faculty:

CCE 3930H – Systems Analysis for Sustainability: Introduction to the principles of sustainable engineering; the use of systems thinking and life-cycle thinking in understanding sustainable systems. Development of sustainability metrics; applications to sustainable transportation, energy-transportation nexus, and electric vehicles.

The UCF Electrical Engineering Department offered two courses as undergraduate electives and entry-level graduate courses.

EEL 4932 Introduction to Smart Grid: Fundamentals of electric power systems, distributed generation and smart grid components, voltage control and VAR compensation, demand response, leader-follower optimization, resiliency.

EEL 6269 Advanced Topics in Power Engineering: Topics on power outages and blackouts, restoration of generation, transmission and distribution, interaction with telecommunication and transportation systems and resilience metrics.

University of Hawaii

The University of Hawaii at Manoa, College of Engineering's Department of Mechanical and Electrical Engineering offered in the fall and spring respectively the following two courses:

ME 610: Renewable Energy Engineering and Sustainability: This course covers the theoretical and technological background of renewable energy generation and distribution and its interactions with sustainability. Students from different science disciplines are the general audience. The emphasis of the course is on solar, biomass, hydro, wind, wave, tidal, geothermal as well as smart grid, storage and electric vehicles.

EE 635: Smart Grids and Renewable Energy Integration: Challenges and solutions for integrating intermittent renewable energy sources into the power system, with a focus on smart grid approaches and demand-response including Electric Vehicles. Using linear programming and other modeling techniques to answer policy-relevant questions.

Tuskegee University

Tuskegee has received TU Senate approval to offer the following 3 credit hour course.

Physics 0570 (3CH) Renewable Energy and Electric Vehicles: Course offered as Physics 499-02 (temporary number) in Spring 2015, 2016, for engineering, chemistry and physics majors.

Tuskegee University Battery Lab

Tuskegee University is in process of setting up a battery laboratory equipped with impedance analyzer, potentiostat, power supply and infra-red camera. This setup will enable students to investigate battery performance changes as well as the temperature effects of battery charging/discharging cycles. Specifically, electrode and electrolyte performances with degradation can be nondestructively characterized by using the impedance spectroscopy setup. The experimental impedance data collected can be used to find out values of parameters for an impedance model for a battery. The resulting variation of impedance parameters directly indicates degree of fades of those components. The IR camera is used to measure temperature changes induced by charging and discharging profiles as well as effects of degradation on temperature rise. Present activities include the ordering of a cylindrical battery holder from Gamry and Tenergy Li-Ion 18650 Battery. All of the results will ultimately augment the understanding of advanced battery chemistry to prepare students for future careers. The lab supports faculty and student lab experiments and student projects.

Workforce Development

As part of the STEM program and STEM presentations, staff has investigated career opportunities related to EVs. The EVTC has also partnered with the Central Florida Clean Cities Coalition on several workforce initiatives that have been offered in partnership with Florida workforce agencies.

In addition, the EVTC has become a stakeholder with two of the five US DOT regional surface transportation workforce centers (TWC): Northeast TWC at the University of Vermont, and Southeast TWC at the University of Memphis. Each TWC will identify critical job needs by reviewing labor market intelligence and reaching out to stakeholders. Each center will also provide information about transportation careers, training and education, and best practices for transportation workforce development within their region. Together, the centers will contribute to a national strategy for transportation workforce development. Each center has a specific focus. The Northeast TWC focus includes climate change and alternative fuels. The Southeast TWC focus includes women in transportation and military/veteran transition to the workforce. The Northeast TWC interviewed EVTC staff member Colleen Kettles about the workforce needs of the electric vehicle industry. The Southeast TWC region covers Florida, and the EVTC is engaged with them as they review their draft "Job Needs and Priorities Report" to be released for our region.

Technology Transfer Accomplishments

As previously reported, UCF and the Central Florida region have established extensive business incubator style programs. These programs are: the Innovative Corps, an NSF funded effort, the Florida Advanced Manufacturing Research Center (FAMRC), a pioneer manufacturing processes and materials center designed to advance the production of smart sensors, and the International Consortium for Advance Manufacturing Research (ICAMR), which is focused on smart sensors and photonics devices. EVTC is continuing to review the U.S. EV manufacturing spectrum for manufacturing locations and technology developments to include workforce considerations.

Diversity Accomplishments

University of Central Florida The primary components of the EVTC diversity program efforts are university education, STEM and K-12 activities, which include curriculum development, professional development for educators and education and outreach to students from underserved communities.

The EVTC program includes STEM project-based learning activities which have an EV focus. Two such programs are the Junior Solar Sprint (JSS) for fourth through eight graders and the Electrathon program, which targets high school and college level students. Junior Solar Sprint involves designing and building a solar powered, model-sized vehicle that is equipped to successfully carry a ping-pong ball (passenger) down the track as quickly as possible. The vehicle is also designed to switch to battery power in the event of overcast skies. The Electrathon is a program where teams design, build and race an electric go-kart that must be driven by a team member and complete as many laps within an hour as possible, without completely draining the vehicle's battery. Both activities are fun hands-on efforts that integrate STEM learning and require problem-solving, critical thinking and teamwork.

Figure 5. Junior Solar Sprint, EnergyWhiz at FSEC, May 14, 2016

Professional development opportunities are offered to teachers and after school program leaders interested in implementing the EV focused, STEM programs. A partnership was formed with the 21st Century Community Learning Centers (CCLC) in Brevard County to include the Junior Solar Sprint (JSS) program as part of their offerings. Professional development opportunities are scheduled for the Spring of 2017 for after school providers and teachers with the focus on the JSS program. These CCLCs are typically based in diverse communities where the need is greatest. FSEC is located within such a community with several Title 1 schools (70% of students participate in the free or reduced lunch program) within walking distance. Student teams that participate in these activities are provided with numerous venues to showcase their work, which also helps to increase awareness about EV's and related careers.

Figure 6. Hillsborough Community College in Tampa, Sep 24, 2016

Education and outreach events, called EnergyWhiz Expos, occurred in various parts of Florida. These events led up to the culminating statewide event called EnergyWhiz occurring at FSEC on May 14, 2016. This event included numerous STEM events, including JSS, Electrathon and the Hydrogen Horizon Automotive Challenge (H2AC). It also included a showcase of EVs and an opportunity to talk one-on-one with proud EV owners. The Electrathon of Tampa Bay group, which organizes racing events throughout Florida has been instrumental in helping EVTC mentor Electrathon teams at Seminole State College (SSC) and UCF. An additional team from Palm Bay High School joined the ranks in April 2016, and participated in the Electrathon race at EnergyWhiz. All three teams are continuing with their efforts for the 2016 – 2017 schoolyear. The UCF team acted as EV ambassadors reaching out to students to engage them in learning more about EVs.

The UCF team worked throughout the 2016 Spring semester to get their vehicle completed in time for the EnergyWhiz statewide event. Despite a valiant effort, the team was unable to compete at the May 14, 2016 event. After a summer hiatus, the team has worked every weekend since the fall semester began to get the vehicle roadworthy for the first race of the 2016 - 2017 school year. The team competed in the first race of the season on September 24, 2016, at Hillsborough Community College. The team also participated in the Drive Electric event held at UCF's main campus in Orlando on September 13, 2016, by exhibiting their Electrathon vehicle, Knightmare on Rainbow Road, and offering test drives to interested students.

Figure 7. University of Central Florida EV Team, from left - Rivera-Matos, Jackson, Gaviria, Henderson, Lopez (driver)

Figure 8. EVTC Electrathon, EnergyWhiz at FSEC, May 14, 2016

The Seminole State College team was unable to compete in the EnergyWhiz Electrathon event held at FSEC on May 14, 2016. However, they continue to work on their vehicle and will have it on the road in early 2017. According to the instructor, James Miller at Seminole State College, the Electrathon program has offered the students in the STEM Club the real-world experience that they have lacked. Students have learned much from planning and improvising through the technical aspects of their Electrathon design.

The biggest gains for the students appear to be in project management and planning, as well as in working within a team, delegating tasks and communicating effectively. The project attracted a number of students with strong theoretical knowledge and time management skills, but very little work or practical application experience. The Electrathon program has provided the hands-on, minds-on experience that the Seminole State College students wanted and needed.

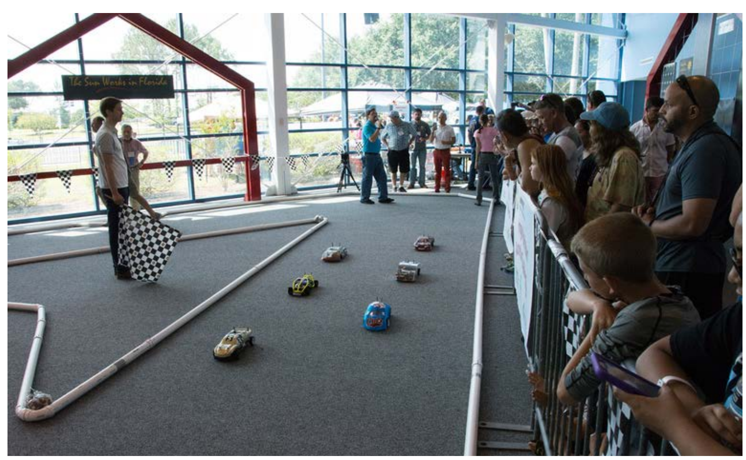

Figure 9. H2 Horizon Automotive Challenge, EnergyWhiz at FSEC, May 14, 2016

EV curriculum development includes both the JSS and Electrathon programs. Efforts to adapt Electrathon lessons are on-going and rely on input from the various Electrathon teams, which is still underway. The JSS curriculum was redesigned to create a supplemental stand-alone unit with more background information and instructions that are conducive to implementation by a wider range of educator skill levels. Although some teachers also provide after school supervision, often that is not the case. Typically these after school care providers have limited STEM knowledge and experience. The JSS materials that have been developed through the EV program fit more appropriately within the skill sets of after school providers and the timeframe of after school programming. Also developed was a "camp kit" that is engaging and works more easily outside the classroom setting.

Tuskegee University

Electric Vehicle Transportation Center (EVTC) Day, June 23, 2016 Tompkins Hall, Tuskegee University

Macon County School students, parents, teachers and administrators attended Tuskegee University's EVTC Workshop in June 2016. Kevin Schleith of UCF gave the keynote address along with special remarks. Academic presentations were given by Dr. Prakash Sharma, head of Tuskegee Physics Department as well as Dr. Zengjun Chen and Dr. A. Kumar.

Robin Gray, executive assistant to the president, and members of the EVTC presented awards to elementary, middle and high school students who participated in the toy model motor making competition. Demonstrations of EV rides and renewable energy were presented by Alabama Power Company.

Figure 10. June EVTC Workshop, presented by Tuskegee Physics Department.

A list of STEM Activities for the period follows:

1. April 2, 2016 – Provided technical assistance for the Central Florida (Orlando) EnergyWhiz Expo event featuring Junior Solar Sprint, Solar Cookoff and Critter Comfort Cottages - approximately 125 participants and attendees
2. April 9, 2016 – Provided technical assistance for the North Florida (Gainesville) EnergyWhiz Expo event featuring Junior Solar Sprint, Solar Cookoff, and Critter Comfort Cottages – approximately 250 participants and attendees
3. April 22, 2016 – Facilitated a session on hydrogen fuel cell technology at the Florida Engineering Educator Conference at UCF, Orlando –for 12 teachers
4. April 30, 2016 – Provided technical assistance for the West Central Florida (Tampa) EnergyWhiz Expo event featuring Junior Solar Sprint and Solar Energy Cookoff – approximately 80 participants and attendees
5. May 14, 2016 – Coordinated and hosted the annual statewide EnergyWhiz event at FSEC in Cocoa. Featured events included Energy Transfer Machine, Junior Solar Sprint, Solar Energy Cookoff, Energy Innovations, Hydrogen Horizon Fuel Cell Race, Critter Comfort Cottage, Electric Vehicle Showcase and Electrathon Race. Over 1000 students, teachers, parents, industry professionals and the public attended or participated in EnergyWhiz.

6. June 7, 2016 – Presented a session at the National Energy Education Summit in Washington, D.C., *EnergyWhiz: Connecting Learning, Schools and Community through Real World Energy Challenges*. –approximately 200 attendees at the summit.
7. June 23, 2016, Facilitated STEM Workshop for Teachers in partnership with FLATE (Florida Advanced Technology Education Center), Hillsborough Community College in Tampa, - 14 Teachers participated.
8. June 23, 2016, EVTC Workshop at Tuskegee University – Solar Electric Cars - 100 attended.
9. July 15, 2016 – Provided tour of EV and other labs at FSEC to students from Eastern Florida State College, - 7 participants
10. July 19, 2016 – Provided tour and hands-on STEM activities to 26 Japanese students
11. August 1-5, 2016, EcoStruction Career Training, Presented information about EVs to 20 participants as part of Sustainability Course.
12. August 25, 2016 – Meeting with Dr. Ethel Newman, Provost at Eastern Florida State College (EFSC) about partnering on EnergyWhiz and Electrathon programs.
13. August 29, 2016 – Meeting with 21st Century Community Learning Center leaders in Brevard to discuss JSS and other STEM activities
14. September 2, 2016 – Meeting with EFSC professors on mentoring and volunteer opportunities for staff and students for EnergyWhiz
15. September 13, 2016 – Drive Electric event at UCF. Staffed an EVTC/FSEC exhibit and provided support to the UCF Electrathon team, which showcased their vehicle.
16. September 22, 2016 –Women in STEAM, Delegation from Israel. Presented information about FSEC and EVTC programs including JSS, Electrathon and how we are working to engage under-represented groups (females, minorities and low income students) in STEAM learning.
17. September 24, 2016 – Electrathon Race and JSS events at Hillsborough Community College, 12 Electrathon vehicles approximately 100 people in attendance at both activities.

Awards

No awards were received during the period.

Metrics

Performance metrics for the EVTC project are designed to drive improvement and characterize progress and effectiveness. The metrics performance table for PPPR#6 with evaluation criteria is provided below.

Metric	Research Activities	Industry Collaboration	Educ. & Workforce Dev.	Tech. Transfer	Diversity
Productivity	EG	EG	EG	EG	EG
Timeliness	S	S	EG	EG	EG
Quality	EG	EG	EG	EG	EG

NI - Needs improvement, S - Satisfactory, EG - Exceeds goals, or C - Completed.

In addition to the above metrics, a part of EVTC peer review has been the continued updating of each project's Schedule F. Using these documents, the EVTC Technical team and project PIs have made their project reviews. Upon completion of the reviews, the written material was used to update the projects and the TRB RiP UTC Research and EVTC websites. These websites are being updated.

What opportunities for training and professional development has the program provided?

Training and professional development activities have been provided to students, industry professionals and the public by the three partner universities. These activities have been previously presented in the Education and Workforce Development Accomplishment sections above and in the following section of results dissemination.

How have the results been disseminated?

Project results have been disseminated by presentations, publications, workshops and conferences.

Presentations:

1. Onat, N., Kucukvar, M., Tatari, O., Egilmez, G., Dynamic Life Cycle Sustainability Assessment Framework for Electric Vehicles in the U.S., Transportation Research Board 95th Annual Meeting, January 10, 2016
2. Katherine McKenzie, Electric Vehicle Transportation and Power Grid Integration, Women in Renewable Energy, January 27, 2016.
3. Katherine McKenzie, Electric Vehicle Transportation and Power Grid Integration, Engineers and Architects of Hawaii, February 26, 2016.
4. Doug Kettles, Electric Vehicle Fleet Implications and Analysis**,** FSEC/UCF, UTC Conference for the Southeast Region, March 31, 2016.
5. Matthieu Dubarry, Devie, A., EV Cell Degradation under Electric Utility Grid Operations: Impact of Calendar Aging & Vehicle to Grid Strategies, Next-Generation Energy Storage 2016, April 18, 2016.
6. Zhihua Qu, Plug-and-Play Operation of Heterogeneous Systems: with Application to Networked Navigation in a GPS Denied Environment, Lockheed Martin MFC, May 27 and June 8, 2016.
7. Katherine McKenzie, Interaction of EVs in a High Renewables Island Grid, HNEI/UH, 2016 IEEE Transportation Electrification Conference and Expo, June 29, 2016.
8. Richard Raustad, EV Workplace Charging: Power Demand...the hidden secret**,** FSEC/UCF, 2016 IEEE Transportation Electrification Conference and Expo, June 29, 2016.
9. Hawk Asgeirsson, Managing EV Load Workplace Charging Project: Utility Perspective, DTE Energy (retired), 2016 IEEE Transportation Electrification Conference and Expo, June 29, 2016.
10. Andrew Meintz, Integrating PEVs with Renewables and the Grid, 2016 IEEE Transportation Electrification Conference and Expo, June 29, 2016.
11. Zhihua Qu, Optimization and Control of Self-Organizing Microgrids, NREL, June 2, 2016
12. Zhihua Qu, Distributed Control for DER Integration: Modularized Design, Plug-and-Play Operation and Security, Workshop on Smart Grid Control, 2016 American Control Conference, July 5, 2016
13. Zhihua Qu, Invited panelist, The National Town Meeting on Demand Response & Smart Grid, July 11-13, 2016 in Washington, DC.
14. Zhihua Qu, “Cooperative Control and Plug-&-Play Operation of Heterogeneous Nonlinear Systems” Seminar at Tokyo Institute of Technology, Tokyo, Japan, August, 2016.
15. Zhihua Qu, “Cooperative Control and Plug-&-Play Operation of Heterogeneous Nonlinear Systems” Seminar at Keio University, Tokyo, Japan, August, 2016.
16. Zhihua Qu, “Power System Resilience: Graph Theoretical Analysis and Power Flow Analysis” Seminar at Keio University, Tokyo, Japan, August, 2016.

Publications:

1. R. Raustad, "Cost Analysis of Workplace Charging for Electric Vehicles," FSEC-CR-2030-16, September 2016. *Project 3*
2. D. Block and P. Brooker, "2015 Electric Vehicle Market Summary and Barriers," FSEC-CR-2027-16, June 2016. *Project 5*
3. M. Dubarry and A. Devie, "Cell Emulation and Preliminary Results," HI-11-16, July 2016. *Project 9*
4. M. Dubarry and A. Devie, "Battery Cycling and Calendar Aging: Year One Testing Results," HI-12-16, July 2016. *Project 9*
5. A. Devie and M. Dubarry, "Durability and Reliability of Electric Vehicle Batteries under Electric Utility Grid Operations. Part 1: Cell-to-Cell Variations and Preliminary Testing," Multidisciplinary Digital Publishing Institute, September 2016. *Project 9*

6. A. Eshraghi, S. Sariri, V. Schwarzer and R. Ghorbani; "Islanding Detection and Over Voltage Mitigation using Wireless Sensor Networks and Electric Vehicle Charging Stations," HNEI-08-15, June 2016. *Project 12*
7. A. Gusrialdi and Z. Qu, "Analysis of Cooperative Systems with Time Delay: Application to Transportation Systems," *IEEE Multi-Conference on Systems and Control*, Buenos Aires, Argentina, September 2016. *Project 13*
8. H. Valizadeh Haghi, S. Lotfifard, and Z. Qu, "Multivariate Predictive Analytics of Wind Power Data for Robust Control of Energy Storage," *IEEE Transactions on Industrial Informatics*, Vol.12, No. 4, pp. 1350-1360, 2016. *Project 13*
9. Y. Joo and Z. Qu, "Cooperative Control of Heterogeneous Multi-agent Systems in Sampled-data Setting", the *55th IEEE Conference on Decision and Control*, ARIA Resort & Casino, Las Vegas, USA, December 2016. *Project 13*
10. R. Harvey and Z., "Cooperative Control and Networked Operation of Passivity-Short Systems," in *Control of Complex Systems: Theory and Applications*, K. G. Vamvoudakis and S. Jagannathan (Eds.), pp. 499-518, Elsevier, Cambridge, MA, 2016. *Project 13*
11. Azwirman Gusrialdi and Zhihua Qu, "Distributed Scheduling and Cooperative Control for Charging of Electric Vehicles at Highway Service Stations," *IEEE Transactions on Intelligent Transportation Systems*, to appear. *Project 13*
12. Nan Qin, Gusrialdi, A. Brooker, P. T-Raissi, A. "Numerical Analysis of Electric Bus Fast Charging Strategies for Demand Reduction," Transportation Research Part A: Policy and Practice, DOI 10.1016/j.tra.2016.09.014. *Project 14.*
13. K. McKenzie, "The State of Electric Vehicles in Hawaii: 2016 Update," HI-09-16, July 2016. *Project 17*
14. B. Sen, T. Ercan and O. Tatari, "Does a battery-electric truck make a difference? – Life cycle emissions, costs, and externality analysis of alternative fuel-powered Class 8 heavy-duty trucks in the United States," *Journal of Cleaner Production*, September 2016. *Project 18.*
15. M. Alirezaei, M. Noor and O. Tatari, "Getting to net zero energy building: Investigating the role of vehicle to home technology," Energy and Buildings, October 2016. *Project 18*
16. M. Coffman, P. Bernstein, S. Wee and A. Arik, "Electric Vehicle Greenhouse Gas Emission Assessment for Hawaii," HNEI-10-16, July 2016. *Project 19*
17. A. Gusrialdi and Z. Qu, "Growing Connected Networks under Privacy Constraint: Achieving Trade-Off between Performance and Security," *the 54th IEEE Conference on Decision and Control*, Osaka, Japan, pp.312-317, December 2015. *Project 20*
18. R. Sarkar, A. Gusrialdi, and Z. Qu,"An Adaptive Restorative Method for Resilient Power Distribution Network," *IEEE PES General Meeting*, 16PESGM2101, Boston MA, USA, July 2016. *Projects 13 and 20.*
19. R. Sarkar, A. Gusrialdi, and Z. Qu, "A Restorative Strategy for Resilient Unbalanced Power Distribution Networks," *North American Power Symposium*, Denver, CO, September 2016. *Projects 13 and 20*
20. Y. Liu, H. Xin, Z. Qu, and D. Gan, "An Attack-Resilient Cooperative Control Strategy of Multiple Distributed Generators in Distribution Networks," *IEEE Transactions on Smart Grid*, 2016. *Project 20*
21. P. Das, D. Chermakani and M. Fripp, "Development of SWITCH-Hawaii Model: Loads and Renewable Resources," HI-13-16, August 2016. *Project 21*

Workshops/Conferences:

1. Tuskegee University EVTC Day, Tuskegee University, June, 2016. Attended by Kevin Schleith
2. 2016 Council of University Transportation Centers, Los Angeles, CA, June 6-8, 2016. Attended by Kevin Schleith
3. National Renewable Energy Laboratory “Smart Mobility” Workshop, hosted by the Clean Cities Program, Golden CO, May 24, 2016. Attended by Colleen Kettles

4. 2016 IEEE Transportation Electrification Conference and Expo, June 27-29, 2016, Dearborn, MI. Attended by Kathrine McKenzie and Richard Raustad as panel speakers.

What do you plan to do during the next reporting period to accomplish the goals?

The R&D program and the research accomplishments for each of the 22 projects are presented in the Accomplishments section. For all active projects, future activities are presented as part of the accomplishments. As previously noted five projects are considered completed. Detailed evaluation are conducted on all remaining program activities and staff. The results have been reported as papers listed on the EVTC website and as upgrades and updates of the TRB RiP and TRID databases.

II. Products

List of products resulting from the program during the reporting period.

Two EVTC Newsletters have been written and distributed by email during this reporting period. The section on "How have results been disseminated?" has presented the information on results dissemination which is also applicable to this section. Thus, reference is made to that section. The other major products are reports on the EVTC website and the TRB RiP and TRID databases. These websites and databases have been kept current with a web and data coordinator individual assigned to post all information. The EVTC web site includes a listing of the current research projects being conducted as well as educational information, technology transfer, news and events, publications, and resources applicable to the overall EVTC project.

III. Participants & Collaborating Organizations

What organizations have been involved as partners?

The three partner universities of the EVTC are the University of Central Florida's Florida Solar Energy Center and UCF's Civil, Environmental and Construction Engineering, Electrical Engineering and Computer Science departments, and the University of Hawai'i at Manoa and the Hawai'i Natural Energy Institute (HNEI) and Tuskegee University.

Organizations that have supplied direct funding to the EVTC are Nissan Motors and NovaCharge, who supplied equipment and funds for installation of a DC fast charging station at FSEC. General Electric Corporation completed computer analysis of Hawaii electrical grid and Alabama Power has supported four Tuskegee University EVTC days. EV Summit sponsors included, Florida Power and Light, Orlando Utilities Commission, Tampa Electric Company, Gulf Power, Charged Electric Vehicles Magazine, Delaware North Corporation (NASA/KSC) and VIA Motors.

What organizations have been involved as collaborative partners?

External organization collaboration efforts have continued by all researchers. The collaborative partners are presented in the External Collaboration Accomplishments section.

IV. Changes/Impact

There are five completed projects. Project 1 (Implications of Electric Vehicle Penetration on Federal and State Highway Revenues), Project 6 (Electric Vehicle Life Cycle Cost Analysis), Project 7 (Assess Existing Software and Databases), Project 19 (Economic Impacts of Electric Vehicle Adoption), and Project 21 (Effect of Electric Vehicles on Power System Expansion and Operation). A funding re-allocation request was sent to DOT in September 2016 due to re-prioritizing and ongoing evaluation of the R&D efforts. The request was approved. One more re-allocation will be required.