Dynamic Capacitive Wireless Power Transfer System for Electric Vehicles

Cooperative Research and Development Final Report

CRADA Number: CRD-12-00480 (Project 9)

NREL Technical Contact: Bingrong Sun

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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Technical Report
NREL/TP-5400-96829
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Cooperative Research and Development Final Report

Report Date: August 22, 2025

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: University of Colorado Boulder

CRADA Number: CRD-12-00480, Project 9

CRADA Title: Dynamic Capacitive Wireless Power Transfer System for Electric Vehicles

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Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Vehicle Technologies Office

Joint Work Statement Funding Table showing DOE commitment:

No NREL shared resources.

Executive Summary of CRADA Work:

Road transportation accounts for 23% of our nation's total energy consumption, 59% of our petroleum consumption and 22% of our total emissions. Electric vehicles (EVs) have much higher well-to-wheel efficiency compared to gasoline vehicles and can reduce our dependence on oil, minimize emissions, improve local air quality and provide a platform for technological innovation and economic growth. While major progress has been made in the development of electric vehicles, their penetration remains under 1 The main hurdles in their widespread adoption are high cost, limited range and long charging times, due to limitations in battery technology. An approach to overcome these hurdles is to substantially reduce the on-board energy storage and instead deliver power wirelessly to the vehicle while it is in motion dynamic wireless power transfer (WPT). For EV charging applications, researchers have traditionally focused on inductive WPT. An issue with inductive WPT systems is that for magnetic flux guidance and shielding, they require ferrite cores, making them expensive, bulky and difficult to embed in the roadway. Under an ARPA-E IDEAS grant, the CU Boulder team has recently

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developed an alternative approach to WPT based on capacitive coupling that is much smaller, lighter, less expensive, and easier to embed in the roadway than inductive WPT; and have demonstrated a 1.2-kW 6.78-MHz version of this capacitive WPT system on a stationary platform. Under this seed grant program, preliminary work will be carried out on a dynamic capacitive WPT system to prepare a strong proposal for the ARPA-E OPEN 2018 FOA.

CRADA benefit to DOE, Participant, and US Taxpayer:

- Assists laboratory in achieving programmatic scope
- Adds new capability to the laboratory's core competencies
- Enhances the laboratory's core competencies
- Uses the laboratory's core competencies

Summary of Research Results:

Task 1: Estimate the Market Potential for Dynamic Power Transfer

The Automotive Deployment Option Projection Tool (ADOPT) will be used to assess the market potential for dynamic electric power transfer. It trades-off vehicle attributes of all the existing vehicle options and additional hypothetical vehicles to estimate technology impacts on future vehicle sales, petroleum use, and emissions. ADOPT will be used to estimate the sales and benefits of dynamic roadway electrification.

While consumers may consider many different vehicle attributes when deciding to purchase a new vehicle, ADOPT assumes that their ultimate decision is primarily driven by a much smaller subset of key factors. The framework varies the importance of these attributes by income to account for the greater sensitivity to cost at lower levels of income, the higher rates of purchase at higher incomes, and the changing level of income over time. Their importance was set to match historical sales. Most of the existing vehicle options were included to enable extensive validation and provide a complete representation of the market. ADOPT's stock model uses the sales to estimate fuel use and emissions. It captures key aspects, including the changing vehicle miles traveled (VMT) as vehicles age, new model option creation, and scrap rates. A simple graphical user interface (GUI) provides access to most inputs and assumptions used by the model, manages scenario setups, and displays results.

ADOPT will model dynamic power transfer vehicles by adding PEVs that have improved range, lower fuel cost, and higher purchase prices. Their attributes will be propagated to additional platforms and adjusted for other technology improvements. The market share of dynamic power transfer vehicles will be evaluated for several fuel prices and levels of technology improvements.

Evaluation Tool

NREL conducted market acceptance analysis to strengthen a proposal for additional funding. NREL used its vehicle choice model, the Automotive Deployment Option Projection Tool (ADOPT), to help evaluate the potential of new technologies.

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ADOPT was used to assess the market potential for dynamic electric power transfer (DPT). It evaluates trade-offs vehicle attributes of all the existing vehicle options and additional hypothetical vehicles to estimate technology impacts on future vehicle sales, petroleum use, and emissions. ADOPT was used to estimate the sales and benefits of dynamic roadway electrification.

While consumers may consider various vehicle attributes when deciding to purchase a new vehicle, ADOPT assumes that their ultimate decision is primarily driven by a much smaller subset of key factors. The framework varies the importance of these attributes by income to account for the greater sensitivity to cost at lower levels of income, the higher rates of purchase at higher incomes, and the changing level of income over time. Their importance was set to match historical sales. Most of the existing vehicle options were included to enable extensive validation and provide a complete representation of the market. ADOPT's stock model uses the sales to estimate fuel use and emissions. It captures key aspects, including the changing vehicle miles traveled (VMT) as vehicles age, new model option creation, and scrap rates. A simple graphical user interface (GUI) provides access to most inputs and assumptions used by the model, manages scenario setups, and displays results.

Evaluation Scenarios

To evaluate the impacts of DPT technology, NREL set up two scenarios: (1) Base scenario, and (2) DPT scenario. In both scenarios, the market share of different vehicle types was predicted from the current year to the year of 2050. The vehicle types included in the evaluation are conventional vehicles (CVs), plug-in hybrid electric vehicles (PLEVs), electric vehicles (EVs), hybrid vehicles (HVs) and fuel-cell vehicles (FCVs).

In the Base scenario, DPT technology is not available.

In the DPT scenario, DPT technology is assumed to be available starting from 2019. To utilize DPT, vehicles need to be equipped with DPT charging components which can increase vehicle cost. Researchers estimated the additional vehicle cost associated with DPT to range between $25 per kilowatts and $43 per kilowatts (Colorado State University 2018). The conservative assumption of $43 per kilowatts was used. Choosing the highest DPT vehicle cost is expected to bring relative conservative evaluation results which provide the lower boundary of DPT benefits. On the other hand, as more vehicles benefit from DPT technology, more travel is made with DPT vehicles. Studies (Aaron Brooker, Eric Wood, Evan Burton, Jeff Gonder, Joann Wang, Mike Simpson 2013) showed that when 1% of the roadway is covered with DPT facilities, 17% of total VMTs would be made by DPT vehicles. Therefore, in this evaluation, the percentage of the VMT made with DPT vehicles was assumed to gradually increase from 0% to 17% between 2025 and 2040 and remain at 17% until the end of evaluation period (year of 2050).

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In addition to the scenario settings, several assumptions were made. One of the key influencing factors that affect people's vehicle purchase choice is the fuel price. In the evaluation, gas and electricity are two major fuels. Their prices were assumed to be the reference prices in 2018 Annual Energy Outlook projected by Energy Information Administration (EIA) (Energy Information Administration 2018). The commercial use price was chosen to represent the electricity price of both traditional charging approaches and the DPT technology. The electricity emission rate was also assumed to gradually decrease to 17% of current year in 2050.

Evaluation Results

Two scenarios described above were implemented in ADOPT. The impacts of DPT technology on future vehicle sales, petroleum use, and emissions were evaluated and discussed in this section.

Annual sales by powertrain

The future annual sales of different vehicle types were predicted until the year of 2050. The sales of each vehicle types in the Base scenario and the DPT scenario were shown in Figure 1. Compared to the Base scenario, EVs have a much larger market share in the DPT scenario. That means the availability of DPT technology has the potential to increase the market share of EVs.

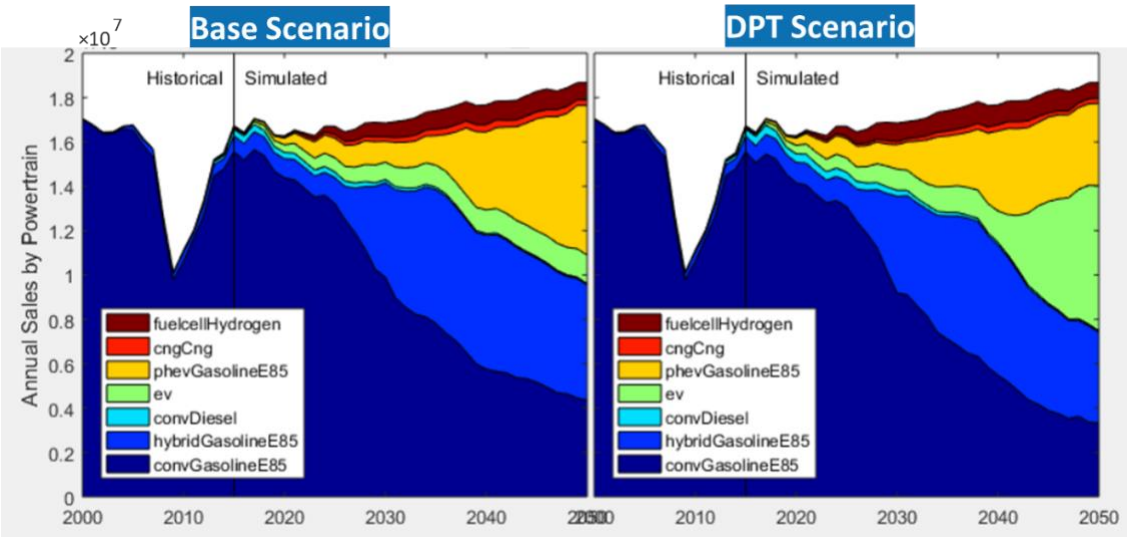

Figure 1 Annual sales by powertrain in Base scenario and DPT scenario

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Best selling vehicles

To have a better understanding of the impacts of DPT technology as well as the reason of increased EV market share, the best-selling vehicle of each vehicle type were also examined. Figure 2 and 3 show the information of the best-selling vehicle in each vehicle type. Each narrow-stacked bar represents the vehicle's generalized cost which is a weighted summation of a group of vehicle features such as price, range, fuel cost, and other factors. The taller the bar is, the less attractive the vehicle is. When comparing the relative height of bars, EVs are more competitive in the DPT scenario than in the Base scenario.

When looking at the performance of specific EV features, as shown in Figure 2, EV's price was reduced from $33,404 in the Base scenario to $28,466 in the DPT scenario. On the other hand, as shown in Figure 3, EV's range was increased from 208 miles in the Base scenario to 411 miles in the DPT scenario. The cheaper price and longer range brought by DPT technology explain the increased annual sale of EVs. An additional benefit was reflected in EV's battery size. In the year of 2050, EV's battery size in the Base scenario is 72 kilowatts-hour. The battery size was decreased to 44 kilowatts-hour in the DPT scenario. DPT technology enables EVs to be charged during traveling thus the battery size can be reduced.

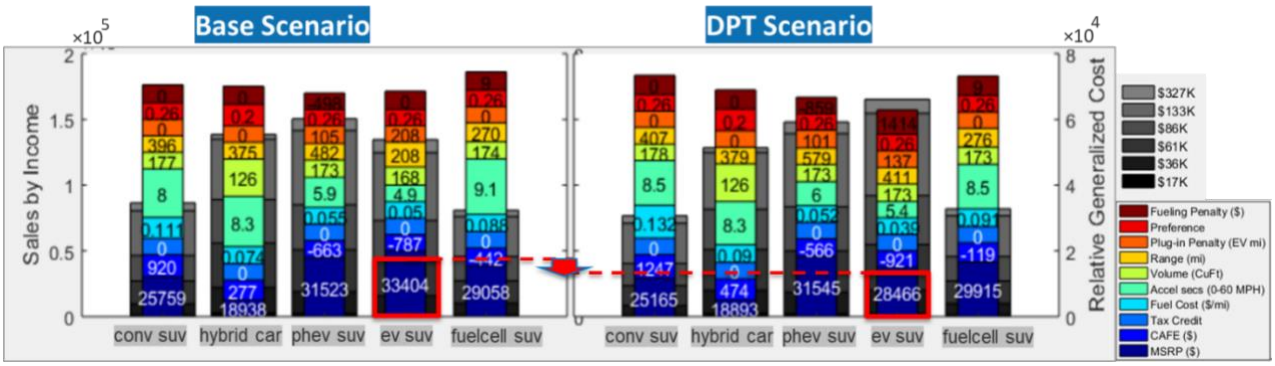

Figure 2 EVs price comparison in Base scenario and DPT scenario

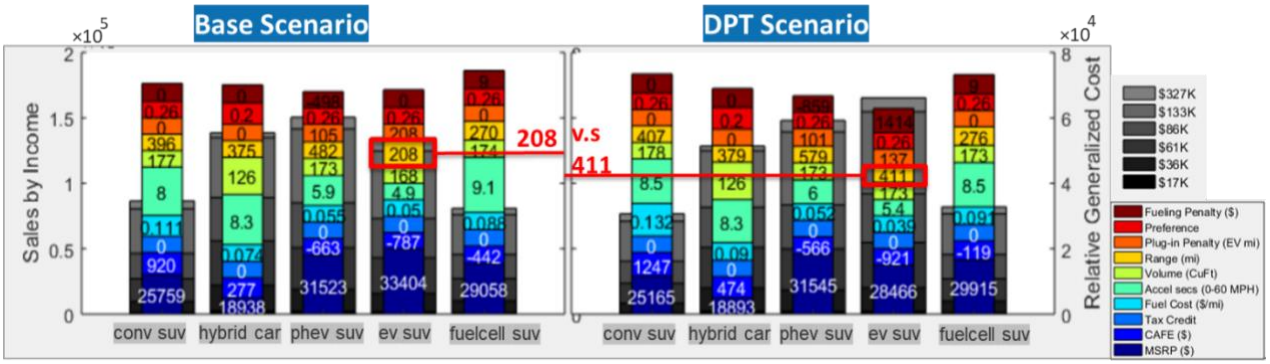

Figure 3 EV range comparison in Base scenario and DPT scenario

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Petroleum consumption

The petroleum consumption of different vehicle types was also evaluated. As shown in Figure 4, by 2050, the DPT scenario has less total petroleum consumption.

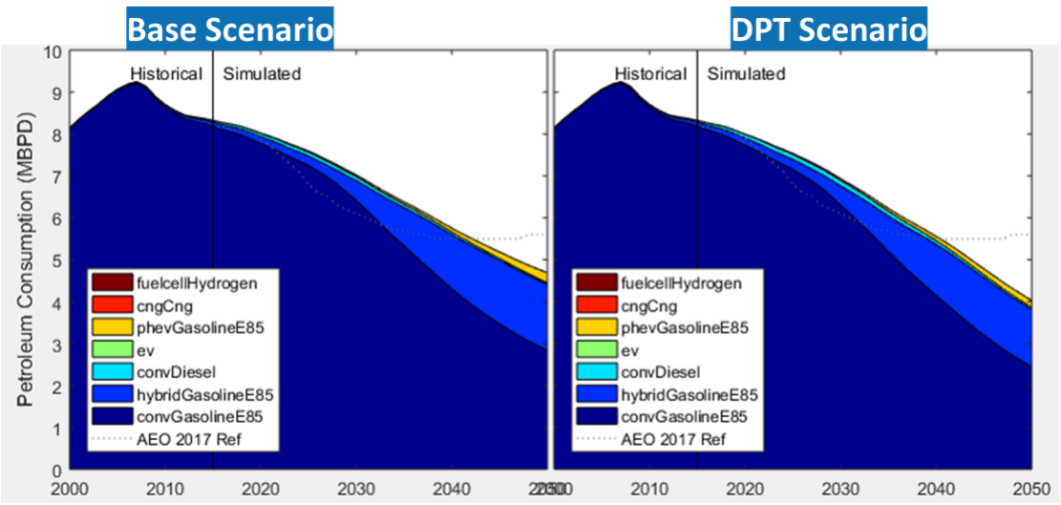

Figure 4 Petroleum consumption in Base scenario and DPT scenario

CO2e emissions

The CO2 equivalent (CO2e) emissions were also evaluated for both scenarios. As shown in Figure 5, the total CO2e emission levels in the DPT scenario are lower compared to the Base scenario.

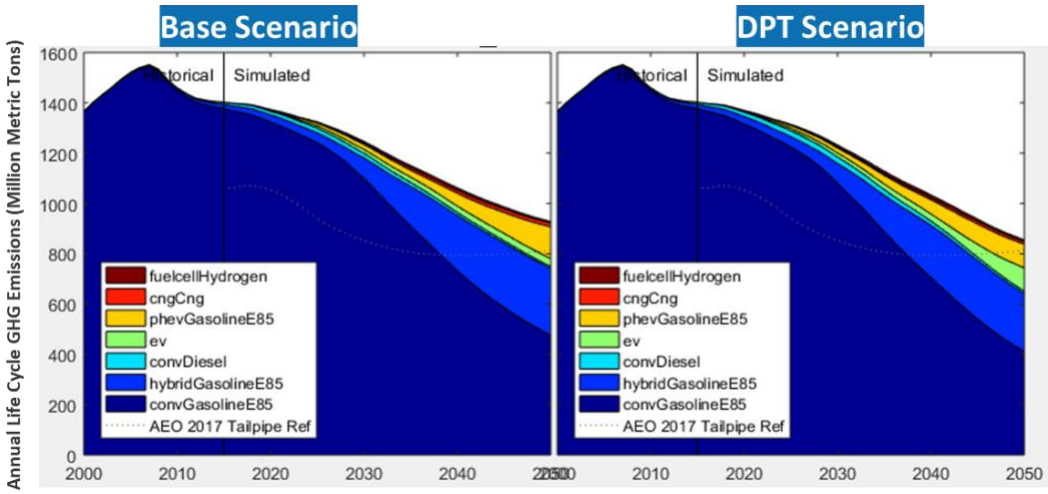

Figure 5 CO2e emissions in Base scenario and DPT scenario

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Conclusions

NREL used ADOPT to estimate the sales and benefits of dynamic roadway electrification. A base scenario and a DPT scenario were evaluated and compared to show the impacts of DPT technology on future vehicle sales, petroleum use, and CO2e emissions.

Evaluation results show that DPT technology has the potential to increase sales of EVs with additional benefits of EVs' lower price, range increase and smaller battery size. In addition, as more vehicles can benefit from DPT technology, the total petroleum consumption and total CO2e emissions are also expected to decrease.

This report serves to meet the requirement for the CRADA Final Report with preparation and submission in accordance with the agreement's Article X.

References:

Brooker, Aaron, Eric Wood, Evan Burton, Jeff Gonder, Joann Wang, Mike Simpson, and Tony Markel. 2013. "Dynamic Wireless Power Transfer Impact Assessment – Draft Analysis Findings." Golden, CO: National Renewable Energy Laboratory.

Colorado State University. 2018. "Capacitive Wireless Power Transfer Costing." Energy Information Administration. 2018. "2018 Annual Energy Outlook." https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3AEO2018&cases=ref2018~highprice~lowprice&sourcekey=0.

Brooker, Aaron, Jeffrey Gonder, Lijuan Wang, Eric Wood, et al. 2015. "FASTSim: A Model to Estimate Vehicle Efficiency, Cost and Performance." SAE International Journal of Engines 8 (2): 2015-01-0973. https://doi.org/10.4271/2015-01-0973.

Brooker, Aaron, Jeffrey Gonder, Samuel Lopp, and Jacob Ward. 2015. "ADOPT: A Historically Validated Light Duty Vehicle Consumer Choice Model." SAE International Journal of Engines 8 (2): 2015-01-0974. https://doi.org/10.4271/2015-01-0974.

Brooker, Aaron, Matthew Thornton, and John Rugh. 2010. "Technology improvement pathways to cost effective vehicle electrification." Presented at SAE World Congress, April 2010.

Wang, Lijuan, Jeffrey Gonder, Aaron Brooker, Andrew Meintz, Alicia Konan, and Tony Markel. 2016. "A Cost Effectiveness Analysis of Quasi-In-Motion Wireless Power Transfer for Plug-In Hybrid Electric Transit Buses from Fleet Perspective." Presented at Conference on Electric Roads & Vehicles (CERV), Logan, UT, May 2016.

Wang, Lijuan, Jeffrey Gonder, Evan Burton, Aaron Brooker, Andrew Meintz, and Alicia Konan. 2015. "A Cost Effectiveness Analysis of Quasi-Static Wireless Power Transfer for Plug-In Hybrid Electric Transit Buses." Presented at IEEE Vehicular Power and Propulsion Conference (VPPC), Montreal, QC, Canada, October 2015.

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Meintz, Andrew, Jeffrey Gonder, Jal Jorgenson, and Aaron Brooker. 2016. "Analyzing Potential Grid Impacts from Future In-Motion Roadway Wireless Power Transfer Scenarios." Presented at Electric Vehicle Symposium and Exhibition (EVS), Montreal, QC, Canada, June 2016.

Subject Inventions Listing:

None.

ROI #:

None.

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