Wind 2H2 Project

Cooperative Research and Development Final Report

CRADA Number: CRD-05-00167 Project 3 (Modification 4, Task 8)

NREL Technical Contacts: Anthony Markel, Ben Kroposki, William Kramer, and Kevin Bennion

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Operated under Contract No. DE-AC36-08GO28308

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Technical Report
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Suggested Citation
Markel, Anthony, Ben Kroposki, William Kramer, Kevin Bennion. 2025. *Wind 2H2 Project: Cooperative Research and Development Final Report, CRADA Number CRD-05-00167 Project 3 (Modification 4, Task 8).* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5T00-97749. https://www.nrel.gov/docs/fy26osti/97749.pdf.

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Cooperative Research and Development Final Report

Report Date: September 23, 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: Xcel Energy Services, Inc.

CRADA Number: CRD-05-00167 Project 3 (Modification 4, Task 8)

CRADA Title: Wind 2H2 Project

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(for Robert Wagner | email n/a – no longer at Xcel Energy

Sponsoring DOE Program Office(s):

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

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources Government In-Kind
Years 1-3 of Project 3, Modification #4*	$50,000.00
TOTAL	$50,000.00

*For Project 3 Mod 4, Task 8 only as part of a multi-project CRADA with other projects under this CRD Number reported and published separately.

Executive Summary of CRADA Work:

The Xcel-NREL Wind Electrolysis R&D Project is designed to gain knowledge and insight about producing hydrogen from electricity for use as a vehicle fuel and as a "stored wind". The project will analyze producing hydrogen directly from wind as well as from the electric grid. In addition, it will look at storing hydrogen and then using it to put electricity back onto the grid.

Modifications were made to the original scope to also include electric vehicles integration with the electric grid. This report addresses Task 8 portion of the CRADA, focused on testing and measuring the attributes of plug-in electric vehicles.

CRADA benefit to DOE, Participant, and US Taxpayer:

The CRADA research provided early insights into plug-in hybrid vehicle technology that was not available anywhere else at the time of the project. The tasks used our existing data collection and analysis capabilities and expanded our knowledge of the state of technology. We used these insights to better guide industry direction and plan research and capabilities that would serve future needs. Through this CRADA we enhance the laboratory's core competencies and improved U.S. competitiveness in PHEV technology.

Summary of Research Results:

Task 8: Xcel Energy PHEV Lab Field Testing and Analysis

The National Renewable Energy Laboratory (NREL) and Xcel Energy collaborated in 2006 to analyze the potential impact of a fleet of plug-in hybrid electric vehicles on the Xcel Energy Colorado territory utility grid operations through a series of simulations. The project report was published as NREL Report No. TP-640-41410. Xcel Energy is proceeding to demonstrate and evaluate the results of this analysis study in a field demonstration.

NREL will conduct tests on six modified Ford Escape Hybrid Vehicles provided by Xcel Energy at the NREL DER Test Facility as budget allows. These vehicles have been modified to allow the vehicles to be plugged into the grid and send and receive power to the grid. Testing will encompass a selected set from IEEE 1547 and UL 1741 to determine interconnection performance of the vehicles. The tests will be agreed to by NREL and Xcel Energy during the development of the test plan. Testing may include response to abnormal over/under voltage and frequency conditions and protection from unintended islanding.

In addition to interconnection testing, NREL will provide technical assistance to complete dynamometer testing to assess the regulated emissions. Dynamometer testing will take place at Environmental Testing Corporation and the costs of this testing will be paid by Xcel Energy. The data will be used to qualitatively assess the relative difference in operational emissions of the PHEV conversions compared to the stock hybrid electric vehicles.

NREL will also provide analysis of vehicle operational data collected from the vehicles on-board data acquisition system during the Xcel Energy PHEV Field test project. During fleet operation, data parameters to be collected from the vehicles while in service may include the following:

Data during key on, (1 sample per second, if possible)	**Data during key off. (1 sample per minute, or greater)**
Time	Time
Lifetime Fuel Consumption	AC current (amps)
Fuel flow rate (g/s)	AC voltage (volts)
Lifetime Odometer (km)	Battery DC current (amps)
Vehicle speed (km/hr)	Battery DC voltage (volts)
Battery DC current (amps)	Ambient Temp (C)
Battery DC voltage (volts)	Battery min/max temps (C)
Ambient Temp (C)	Battery SOC (%)
Battery min/max temps (C)	Battery Energy Available Discharge (kWh)
Battery SOC (%)	Battery Energy Available Charge (kWh)
Latitude (decimal deg)	Latitude (decimal deg)
Longitude (decimal deg)	Longitude (decimal deg)
Elevation (m)	Elevation (m)
Engine Temp (C)	Lifetime AC In (kWh)
Motor torque (Nm)	Lifetime AC Out (kWh)
Generator speed (rpm)	Plug Connection Engaged
Engine speed (RPM)	Accessories ON (Headlights, hazards, etc.)(and current use)
Battery Charge Limit (kW or amps)	
Battery Discharge limit (kW or amps)	
Engine Coolant Temp (C)	
Brake pedal (%)	
Accel pedal (%)	
Accessories ON (AC, Heat, etc.)(and current use)	

Based on data collected in field operation, NREL will

- Define vehicle usage profiles for each vehicle in the study.
- Quantify the variability in vehicle usage for each vehicles in the study
- Identify vehicle recharge profiles without utility control
- Identify vehicle recharge profiles with utility control
- Assess the ability of each vehicle to respond to utility dispatch commands
- Quantify impact of utility dispatch commands on fuel consumption
- Characterize roundtrip efficiency of vehicle to grid energy delivery
- Summarize the cost of operation of the PHEVs.

Summary and Outcomes of CRADA Task 8

Within task 8, the research team leveraged early models of PHEVs that we developed from converted hybrid electric vehicles. The added grid interconnectivity controllability of these vehicles was unique and provided significant value to the NREL research outcomes.

As scoped, NREL conducted limited emissions testing of these prototype vehicles. The measurements were provided to Xcel Energy but not published as these were prototypes conversions and not fully representative of a commercial product.

Additionally, limited testing of the grid interconnection capabilities was completed. The goal was to understand if these converted plug-in electric vehicles were compatible with existing IEEE 1547 interconnection standards for inverters or if modifications to either the vehicle or standards would be needed. A key outcome of this effort was the development of a test plan and procedures that would be later used for future vehicle testing. The insights contributed to a publication later of interim test procedures specifically for vehicle to grid functions in electric vehicles.[0]

Finally, NREL and Xcel researchers collaborated on collection and analysis of operational data from in-use plug-in hybrid electric vehicles. The unique aspect of this work was also the ability to communicate with the vehicles and uses to adjust the charging profiles while still meeting the driver's expectations. This was the first of its kind and the results of these efforts were published.[0]

A field study was conducted with a group of six vehicles of which three provided valuable data. Data was collected over a 16-week period in which 10 charge management scenarios were tested. Even within this small test fleet, data was sufficient to support the prior conclusions drawn by the analysis of the simulation study completed in 2007(0). The team was even able to test an expanded set of load control shapes tied to renewable resources, real-time price, and grid ancillary service needs. Fuel savings observed in the field correlated well with those previously estimated in the range of 25-50% reduction relative to the comparable hybrid vehicles.

Figure 1 below was a key conclusion of this work. For utilities to use vehicles as a grid resource, those vehicles in aggregate would need to be able to offer a consistent resource of either energy charge or discharge capacity. The figure shows 3 weeks of data for 3 vehicles in aggregate. The fluctuation of storage charge and discharge capacity varied significantly. This can be resolved with more vehicles in aggregate, more available charging infrastructure and charge management algorithms that account for both user and grid expected needs.

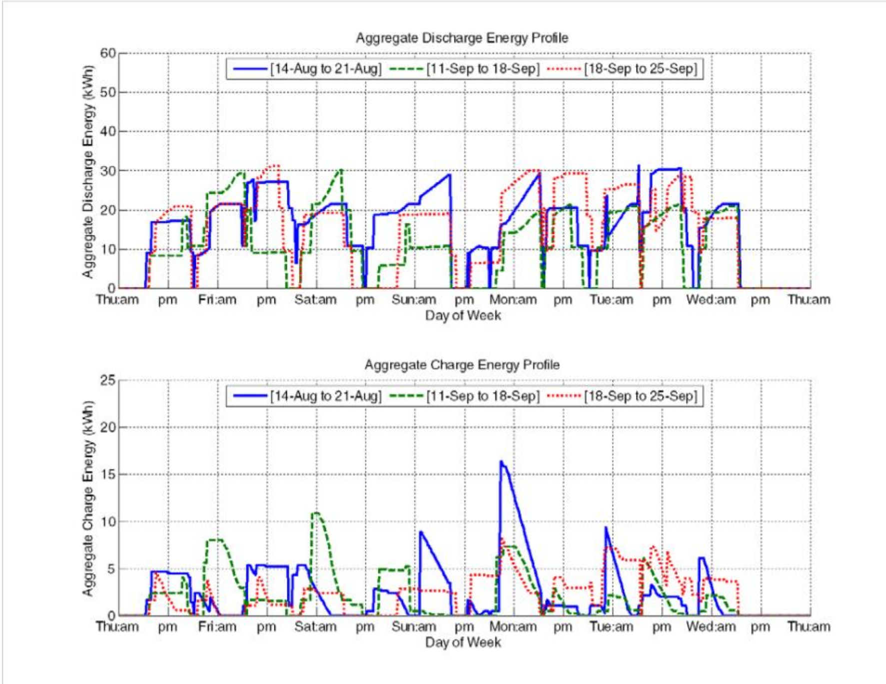

Figure 1: Charge and Discharge Aggregate Capacities of the Test Fleet during Weeks 5, 9, and 10 (Figure 8 in NREL report 46345)

Those efforts in task 8 were completed successfully in collaboration with Xcel Energy and insights and outcomes were published. The work influenced the direction of future research proposals and the development of vehicle testing capabilities within the Energy Systems Integration Facility at NREL.

Task 9: Note Task 9 listed on the Executed Agreement Mod 4(Project 3) was amended to be included in Mod 6 (Project 1).

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:

Field Testing Plug-in Hybrid Electric Vehicles with Charge Control Technology in the Xcel Energy Territory. 2009. https://www.nrel.gov/docs/fy09osti/46345.pdf

Interim Test Procedures for Evaluating Electrical Performance and Grid Integration of Vehicle-to-Grid Applications. 2011. https://www.nrel.gov/docs/fy11osti/51001.pdf

Costs and Emissions Associated with Plug-In Hybrid Electric Vehicle Charging in the Xcel Energy Colorado Service Territory.2007.https://www.nrel.gov/docs/fy07osti/41410.pdf. TP-640-41410.

Subject Inventions Listing: None

ROI#: None