National Renewable Energy Laboratory
*Innovation for Our Energy Future*

*A national laboratory of the U.S. Department of Energy*
*Office of Energy Efficiency & Renewable Energy*

# PHEV Impacts on Regional Systems

## Goals

As a result of additional PHEV loading, quantify the following items:

- Avoided gasoline
- Distribution impacts (feeder and bank loading)
- Increased utilization of existing infrastructure
- Vehicle emission footprint

## Problem Definition

Plug-in hybrid electric vehicles (PHEVs) offer an intriguing solution to displacing oil, off-setting emissions, and benefiting both the utility and customer with cost savings. While impacts can be generalized, specific costs and benefits are relatively unknown. Using the Xcel Energy Colorado service territory and customer base as a proxy to estimate these impacts will help further knowledge and benefits of PHEV technology.

## Results

The study quantifies benefits to the utility and the consumer for plug-in hybrid electric vehicles. PHEVs have implications at the individual and societal level regarding reduced gasoline consumption, vehicle operating cost reductions, and lower emissions. Xcel Energy can control impacts while increasing sales through modest incentives or controls.

### Charging Profiles

The timing of charging reflects real driving patterns with and without incentives and/or controls. Three of the four charging profiles represent charge at home scenarios (Do Nothing, Delay to 10pm, Optimized to Off-Peak); the last (Opportunity Charging) assumes vehicles have access to plugs throughout the day. Typical vehicle consumption for charge at home scenarios is 5.3 kWh/dayt (1.9 MWh/yr). For opportunity charging, consumption goes up 75% to 9.4 kWh/day (3.4 MWh/yr).

## Solution Concept

Develop PHEV charging profiles derived from actual GPS-tracked vehicles simulated to be PHEV with a 9.0kWh battery (ie PHEV20 ) using NREL's ADVISOR vehicle simulation model. Simulate the Xcel Energy Colorado system assuming various penetrations and charging strategies of PHEVs using PROSYM, a chronological production cost model. Develop a PHEV load analysis tool to analyze capacity impacts at the system, bank, and feeder level.

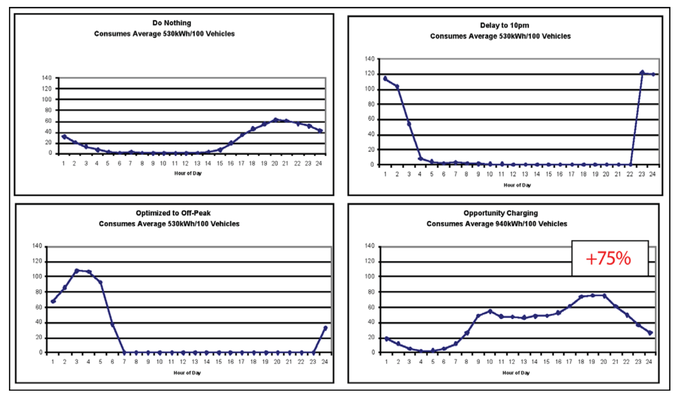


*Figure 1. Charging Profiles*

Four different charging regimes were analyzed:

1. Do Nothing* – Vehicles leave the for day; return home and begin charging immediately
2. Delay to 10pm* – As above, but a timer delays charging until 10pm
3. Optimize to Off-Peak* – As above, but control vehicle charging to occur in the lowest load hours.
4. Opportunity Charging – Vehicles have access to the grid throughout the day charging whenever they are parked.

*Options one through three represent charge at home regimes

The resulting loading profiles were scaled to simulate penetrations of 50k, 250k, and 500k vehicles corresponding to 3%, 15%, and 30% penetration of household vehicles in the Xcel Energy Colorado service territory.

### Avoided Gasoline

The largest single benefit is reduced gasoline consuption for the consumer. For charge at home regimes, 55% of fleet gasoline consumption is avoided. With opportunity charging, 73% of gasoline is avoided. At $3/gallon gasoline and $0.09/kWh electricity, that translates to annual consumer savings of $710 and $860 respectively. At 50k vehicles, or 3% penetration of household vehicles, the annual household savings is $35.5M and $43M. Increased electricity consumption translates to 96.7 GWh and 171.5 GWh annually.

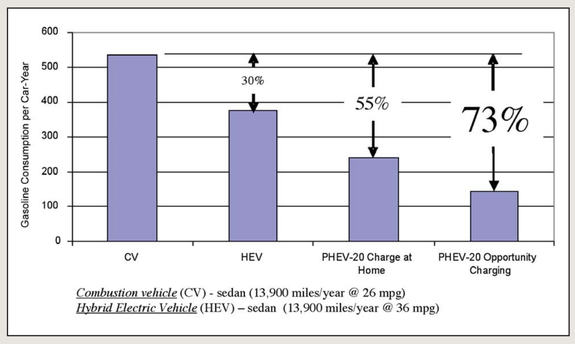


*Figure 2. Comparative Fuel Consumption for PHEVs*

### Production Costs

The additional load due to PHEVs will result in additional production costs. The timing of the charging matters. As charging is pushed to the off-peak, production costs decline. Fuel costs dominate the total costs. By implementing a program to encourage off-peak charging, Xcel Energy could save $53/car annually by optimizing dispatch of the vehicle, or $41/car annually by delaying charging to 10pm. At 50k vehicles, this is $2.65M and $2.05M annual savings.

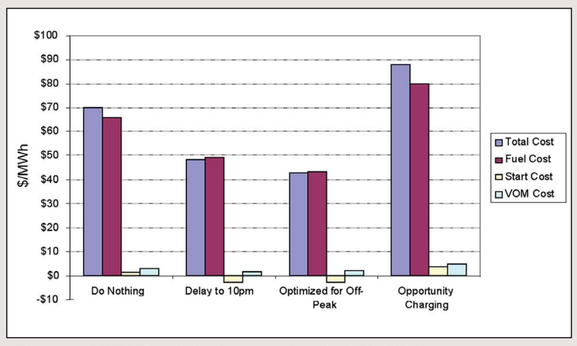


*Figure 3. PHEV Electricity Average Cost (50k Vehicle)*

### Emission Footprint – Utility Scale

Since PHEVs substitute electric-drive for gasoline-drive, they will displace tailpipe emissions upsteam to Xcel Energy. The total amount of emissions depends on the number of vehicles and the timing of the charging. Emissions go up as charging is pushed further into the off-peak period. Opportunity charging has the largest total CO2 emissions, largely due to the larger total energy consumed. Total PHEV emissions is small compared to total electricity sector emissions.

The emission rate associated with different charging regimes has the same pattern; as charging is pushed to the off-peak, the emission rate goes up. This is due to more coal being used to supply power for the PHEVs.

Note the incremental emission rate is less than half of the system average emission rates. That is, incremental generation reduces the average emission rate.

### Emission Footprint – Vehicle Scale

The vehicle emission footprint includes tailpipe emissions (aka vehicle), upsteam utility emissions, and upsteam gasoline refinery emissions. The PHEV total emission for NOx, SOx, and CO2 goes down relative to future combustion vehicles and hybrid electric vehicles for most charging regimes. The notable exception is the Optimized to Off-Peak charging scenario which has nominally more NOx and SOx emissions (but marked reductions in CO2). To contrast, the Opportunity Charging regime has the greatest reduction of emissions for all emissions. The tailpipe emissions are reduced in all charging cases. This is significant with regard to urban air-shed issues, or the amount of emissions released in or near urban areas.

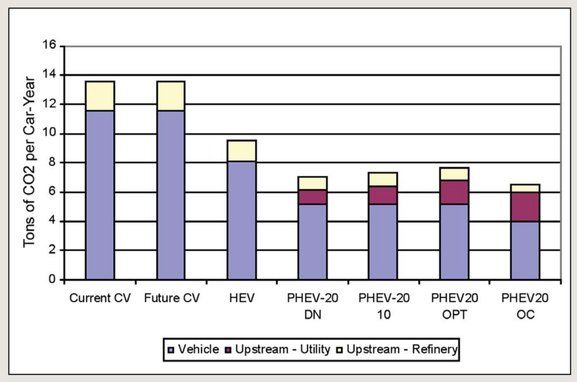


*Figure 4. Comparative CO2 Emissions for Regional System*

## Benefit Analysis

The total benefit of PHEVs to Xcel Energy is a mixed bag. In the Optimized to Off-Peak scenario, costs can be saved in exchange for nominal increase in total emissions. For Opportunity Charging, the most gasoline is avoided combined with the most emission reductions with more total electricity sales. The trade-off is this scenario has the highest production and capacity cost impacts. Delay to 10pm is a compromise of these two extreme cases providing cost savings while providing equal or less total emissions. Do Nothing has lower emissions, higher production costs, and additional capacity costs.




*Figure 5. Upstream Emission Rates Impact of PHEVs (50k Vehicles)*

**CONTACTS**
Keith Parks, Paul Denholm, and Tony Markel
**National Renewable Energy Laboratory (NREL)**
1617 Cole Blvd.
Golden, CO 80401-3393
keith_parks@nrel.gov, paul_denholm@nrel.gov,
tony_markel@nrel.gov

**The information contained in this poster is subject to a government license.**
**CU Energy Initiative/NREL Symposium**
**University of Colorado, Boulder**
**October 3, 2006**
**NREL/PO-640-40694**

SEAC Strategic Energy Analysis Center