Environmental Assessment of Plug-In Hybrid Electric Vehicles

Volume 1: Nationwide Greenhouse Gas Emissions

Environmental Assessment of Plug-in Hybrid Electric Vehicles

In the most comprehensive environmental assessment of electric transportation to date, the Electric Power Research Institute (EPRI) and the Natural Resources Defense Council (NRDC) are examining the greenhouse gas emissions and air quality impacts of plug-in hybrid electric vehicles (PHEV). The purpose of the program is to evaluate the nationwide environmental impacts of potentially large numbers of PHEVs over a time period of 2010 to 2050. The year 2010 is assumed to be the first year PHEVs would become available in the U.S. market, while 2050 would allow the technology sufficient time to fully penetrate the U.S. vehicle fleet.

A Collaborative Study

The objectives of this study are the following:

- Understand the impact of widespread PHEV adoption on full fuel-cycle greenhouse gas emissions from the nationwide vehicle fleet.
- Model the impact of a high level of PHEV adoption on nationwide air quality.
- Develop a consistent analysis methodology for scientific determination of the environmental impact of future vehicle technology and electric sector scenarios.

NRDC and EPRI collaborated to conduct this eighteen-month study. The scenarios and key study parameters were generated, analyzed, and approved by both organizations. NRDC contributed its substantial experience in wide-ranging environmental studies, EPRI its operating knowledge of the electric sector and prior simulation and modeling work on plug-in hybrids[1]. Both organizations analyzed, reviewed, and approved of the resulting data and report findings.

Two Study Components, Two Reports

Phase 1 of the study, completed in July 2007, has two major components. The first is a scenario-based modeling analysis to determine the greenhouse gas emissions impacts of PHEVs over a timeframe of 2010 to 2050. The second component is a nationwide air quality analysis for the year 2030 that assumes an aggressive market penetration of PHEVs.

The methodology and findings of these two analyses are presented separately in two technical reports:

- Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 1: Nationwide Greenhouse Gas Emissions (1015325)

1 Initial study data on PHEV performance characteristics and on future power plant technology availability and performance were drawn from prior EPRI work.

- Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 2: United States Air Quality Analysis Based on AEO-2006 Assumptions for 2030 (1015326)

PHEV Impact on Nationwide Greenhouse Gas Emissions

Overview of Study and Results

This report describes the first detailed, nationwide analysis of greenhouse gas (GHG) impacts of plug-in hybrid electric vehicles. The "well-to-wheels" analysis accounted for emissions from the generation of electricity to charge PHEV batteries and from the production, distribution and consumption of gasoline and diesel motor fuels.

Researchers used detailed models of the U.S. electric and transportation sectors and created a series of scenarios to examine assumed changes in both sectors over the 2010 to 2050 timeframe of the study.

- Three scenarios represent high, medium, and low levels of both CO_2 and total GHG[2] emissions intensity for the electric sector as determined by the mix of generating technologies and other factors.
- Three scenarios represent high, medium, and low penetration of PHEVs in the 2010 to 2050 timeframe.

From these two sets of scenarios emerge nine different outcomes spanning the potential long-term GHG emissions impacts of PHEVs, as shown in the following table.

Annual greenhouse gas emissions reductions from PHEVs in the year 2050.

2050 Annual GHG Reduction (million metric tons)		Electric Sector CO_2 Intensity		
		High	Medium	Low
PHEV Fleet Penetration	Low	163	177	193
	Medium	394	468	478
	High	474	517	612

Researchers drew the following conclusions from the modeling exercises:

- Annual and cumulative GHG emissions are reduced significantly across each of the nine scenario combinations.
- Annual GHG emissions reductions were significant in every scenario combination of the study, reaching a maximum reduction of 612 million metric tons in 2050 (High PHEV fleet penetration, Low electric sector CO_2 intensity case).
- Cumulative GHG emissions reductions from 2010 to 2050 can range from 3.4 to 10.3 billion metric tons.
- Each region of the country will yield reductions in GHG emissions.

More detailed results are presented below and in Chapter 5 of this report.

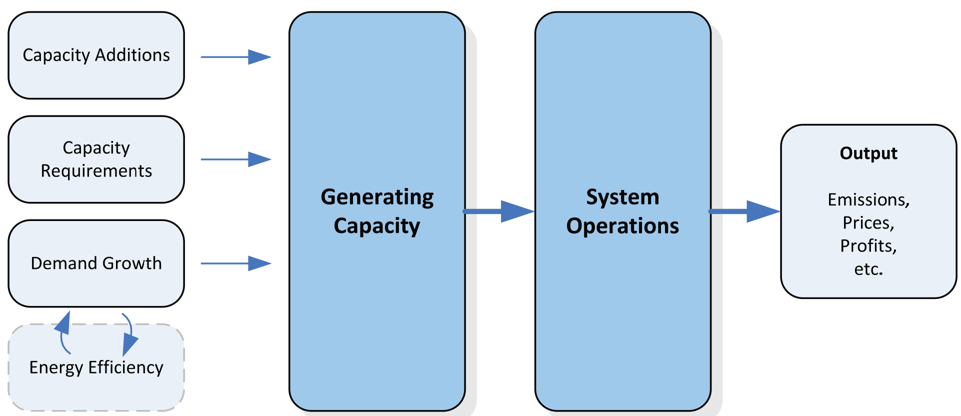
2 CO_2 is the dominant greenhouse gas resulting from operation of natural gas and coal-fired power plants. Full fuel cycle GHG emissions include N_2O and CH_4, primarily from upstream processes related to the production and transport of the fuel source.

Study Methodology

The project team developed detailed and comprehensive models of the U.S. electric and transportation sectors that simulated the evolution of both sectors over the 2010 to 2050 study timeframe. The researchers also developed a series of scenarios to assess the impact of PHEVs over a range of different possible futures depending on the evolution of the energy and transportation sectors.

Electric Sector Model

To determine the GHG emissions from the electricity generated to charge PHEV batteries, EPRI developed a modeling framework that provides a detailed simulation of the electric sector. The EPRI framework integrates two sophisticated computer models. The first model, the Energy Information Agency's National Energy Modeling System (NEMS) covers the entire U.S. energy-economy system and calculates energy supply and demand nationwide. NEMS outputs—prices and electric loads—are the inputs to the second model, the EPRI National Electric System Simulation Integrated Evaluator (NESSIE). The NESSIE model represents the U.S. electricity sector from 2010 to 2050.



Structure of U.S. Electric Sector Model (NESSIE)

The model simulates decisions to add new capacity and to retire existing capacity. This component is extremely important for tracking the evolution of the generation capacity over time as it serves existing load and new load from PHEV charging. New generating capacity is generally lower in GHG emissions than existing capacity. Capacity retirements increase the rate at which newer, lower emitting capacity is created. In addition, NESSIE simulates how technologies change over time, including gradual performance improvements for commercially available technologies such as combustion turbines or the emergence of advanced technologies such as Integrated Gasification Combined Cycle (IGCC) coal plants. Technology improvement is an important factor for reducing the GHG intensity of the future electric grid.

After simulating capacity additions and retirements, the model operates this capacity to meet electricity demand. Electric sector analysts call this a "production simulation" or "dispatch." The load varies across the year. Each generating technology has a bid price for energy that it offers to the market based on its variable cost of production. The market selects the lowest possible bids. The price for all operating generators is set by the technology with the highest bid price that is operating at the time. This production simulation identifies the load served by every technology, cost of electricity, and emissions of SO_2, NOx, Hg, and GHG.

The electric sector model of the United States is divided into 13 distinct study regions based on the North American Electric Reliability Corporation (NERC) Regional Reliability Councils and Federal Energy Regulatory Commission (FERC) regions. The representation of these regions allows a careful accounting of how different regional capacity mixes affect GHG emissions.

Electric Sector Scenarios

The future of the U.S. electric sector may follow different paths, depending on the evolution of environmental policies, electricity demand, and available technologies. Rather than trying to develop a single consensus view, the team created three scenarios to span the impact of PHEVs over different possible futures.

The scenarios represent different levels of CO_2 intensity for the sector.

1. High CO_2 intensity scenario: There is limited availability of higher efficiency and non-emitting generation technologies and a low cost associated with allowances to emit CO_2 and other GHGs in this scenario. Total annual electric sector GHG emissions increase by 25% from 2010 to 2050.
2. Medium CO_2 intensity scenario: Advanced renewable and non-emitting generation technologies, such as biomass and IGCC with carbon capture and storage, are available in this scenario. There is a moderate cost associated with allowances to emit CO_2 and other GHGs. Total annual electric sector emissions decline by 41% between 2010 and 2050.
3. Low CO_2 scenario: Carbon capture and storage retrofit technology for existing coal plants are available in this scenario. In addition, there is significantly slower load growth indicative of a nationwide adoption of energy efficiency, or other demand reduction, and a high cost to emit CO_2 and other GHGs. Total electric sector emissions decline by 85% in this scenario from 2010 to 2050.

The NESSIE model was used to model each of the above scenarios and to output the detailed results. Each scenario used a different set of input data and was run through the entire model to produce the measures of interest. The following table shows the key differences among electric sector scenarios.

Key parameters of the High, Medium, and Low CO_2 Intensity electric scenarios.

Scenario Definition	High CO_2 Intensity	Medium CO_2 Intensity	Low CO_2 Intensity
Price of Greenhouse Gas Emission Allowances	Low	Moderate	High
Power Plant Retirements	Slower	Normal	Faster
New Generation Technologies	Unavailable: Coal with CCS New Nuclear New Biomass	Available: IGCC Coal with CCS New Nuclear New Biomass Advanced Renewables	Available: Retrofit of CCS to Existing IGCC and PC Plants
	Lower Performance: SCPC, CCNG, GT, Wind, and Solar	Nominal EPRI Performance Assumptions	Higher Performance: Wind and Solar
Annual Electricity Demand Growth	1.56% per year on average	1.56% per year on average	2010-2025: 0.45% 2025-2050: None

PC – Pulverized Coal
SCPC – Supercritical Pulverized Coal
CCNG – Combined Cycle Natural Gas
GT – Gas Turbine (Natural Gas)
CCS – Carbon Capture and Storage

Vehicle Emissions Model

The vehicle emissions model represents the energy consumption and other performance attributes of three vehicle types: PHEVs, hybrid electric vehicles (HEVs), and conventional vehicles (CV) powered by internal combustion engines. The model also represents the penetration rate of each configuration across multiple vehicle categories (passenger cars to light trucks) throughout the 48 continental United States over the 2010-2050 timeframe.

The study assumes that PHEVs will be available in vehicles up to 19,500 lb gross vehicle weight (Class 5 Heavy Duty Vehicles). PHEVs will also be available in configurations offering different levels of electric range—the number of miles a vehicle can travel on the energy in its battery for a single charge. A vehicle's electric range is denoted by attaching the electric range after the term PHEV. For example, a PHEV 10 is a plug-in hybrid with 10 miles of electric range.

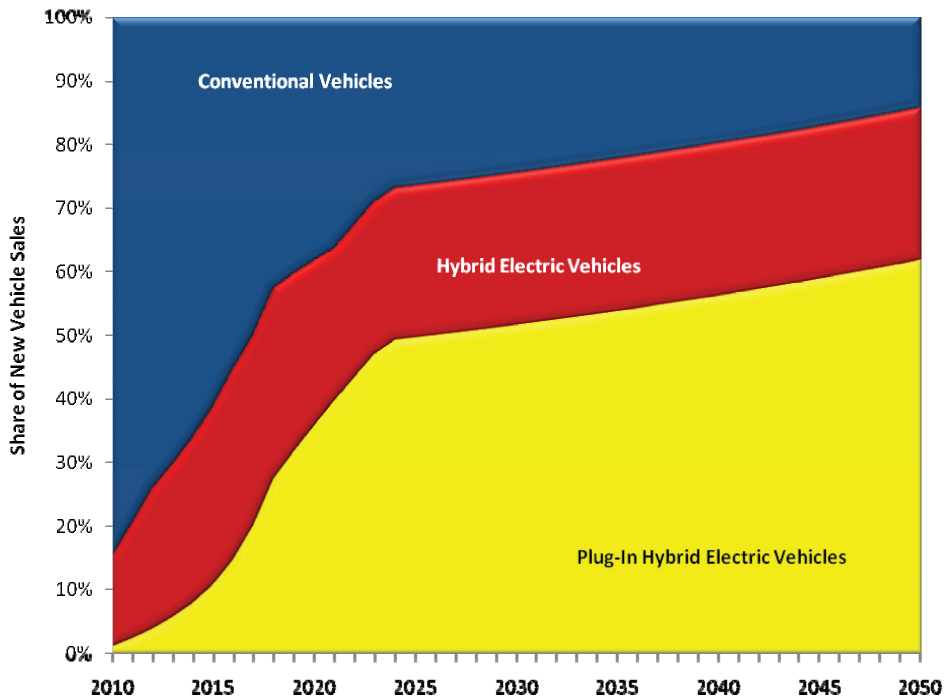
The use of electricity is an important attribute of PHEVs. Use of electricity reduces both gasoline consumption and emissions—starting emissions, refueling emissions, running emissions and even upstream refinery emissions.

Market Adoption

The project team developed three distinct market adoption scenarios, each based on PHEVs entering the market in 2010 and achieving maximum new vehicle market share in 2050. As shown in the following table, PHEVs reach a maximum of 20% new vehicle market share in the Low PHEV scenario, 62% in the Medium PHEV scenario, and 80% in the High PHEV scenario.

Peak new vehicle market share in 2050 for the three PHEV adoption scenarios

2050 New Vehicle Market Share by Scenario		Vehicle Type		
		Conventional	Hybrid	Plug-In Hybrid
PHEV Fleet Penetration Scenario	Low PHEV Fleet Penetration	56%	24%	20%
	Medium PHEV Fleet Penetration	14%	24%	62%
	High PHEV Fleet Penetration	5%	15%	80%

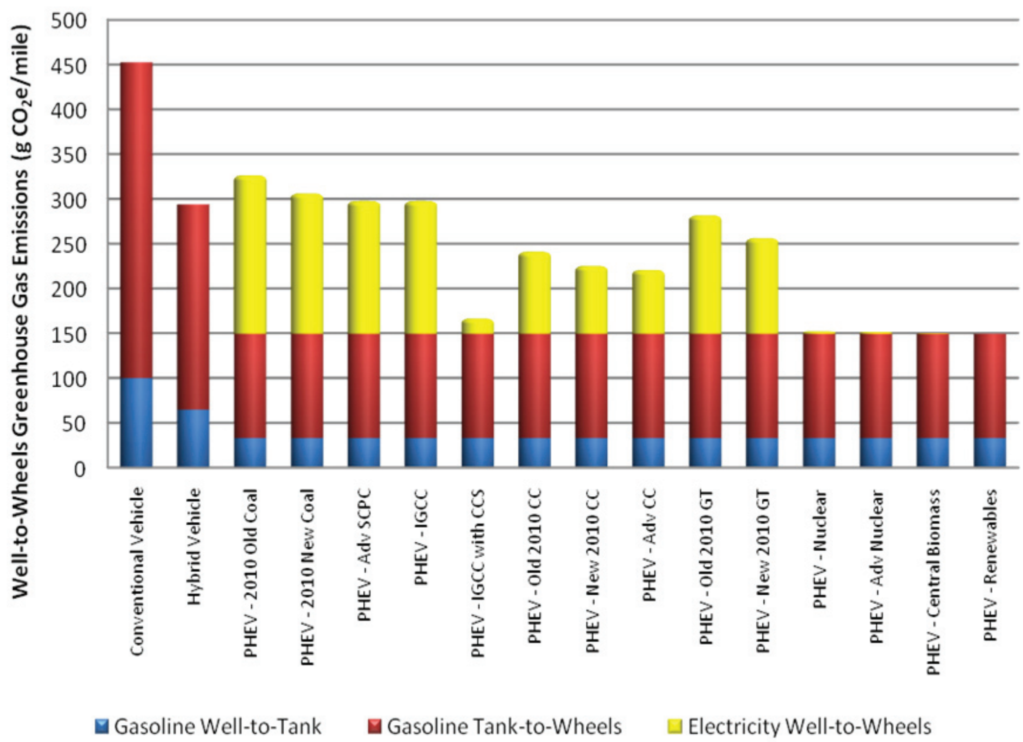


Assumed new car market share for the Medium PHEV scenario for conventional vehicles, hybrid electric vehicles, and plug-in hybrid electric vehicles for each vehicle category

Results

Emissions Decline as Electric and Transportation Sectors Evolve

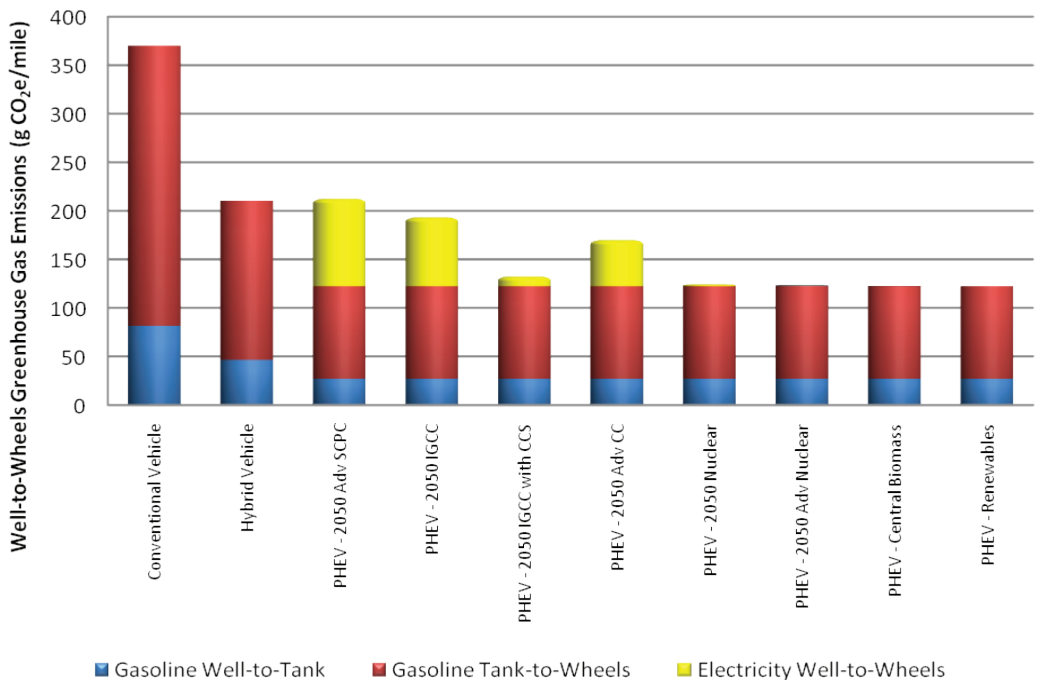
The study generated a wealth of information that enables researchers to examine the GHG emissions impacts of different vehicle categories and generating technologies over time. The following figure is a year 2010 comparison of total GHG emissions from conventional vehicles, hybrid electric vehicles, and a PHEV with 20 miles of all-electric range for a typical case of 12,000 miles driven per year. For PHEVs, the figure includes GHG emissions associated with all-electric and hybrid-electric operation.



Year 2010 comparison of PHEV 20 GHG emissions when charged entirely with electricity from specific power plant technologies (12,000 miles driven per year).

From this figure, it is clear that the carbon intensity of the generation technology plays a significant role in the total GHG emissions from PHEVs. In 2010, current coal technologies result in 28% to 34% lower GHG emissions compared to the conventional vehicle and 1% to 11% higher GHG emissions compared to the hybrid electric vehicle.

In year 2050, however, GHG emissions fall as higher emitting technologies are assumed to phase out of the electric generating fleet. In 2050, vehicle efficiency has improved, so all three components of well-to-wheel GHG emissions are lower. The PHEV 20 produces approximately the same GHG emissions as an HEV if powered by electricity from coal-fired power plants that do not capture CO_2, and has 37% lower GHG emissions than the HEV if powered by coal-fired power plants with CO_2 capture and storage.



Year 2050 comparison of PHEV 20 GHG emissions charged entirely with electricity from specific power plant technologies (12,000 miles driven per year)

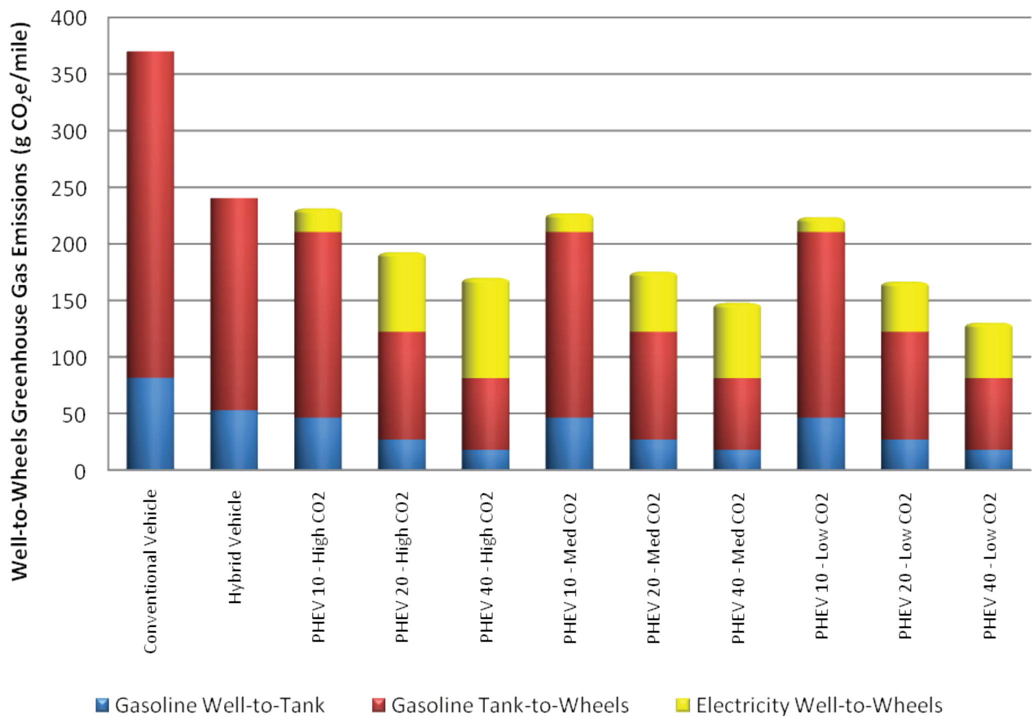
Electric Sector Simulation Results

The preceding examples show the strong dependence of PHEV GHG emissions on the source of electricity. In reality, PHEVs will not be drawing power solely from individual generating technologies but rather from a mix of resources that include fossil, nuclear, hydroelectric and renewable technologies.

Total system emissions from a given level of PHEV use will be determined by a combination of the vehicle type (PHEV with a 10, 20 or 40 miles of electric range), annual vehicle miles traveled by vehicle type, and the types of generating resources that are built and dispatched to serve the electrical load from grid-connected PHEVs.

The following figure compares GHG emissions of model year 2050 conventional and hybrid vehicles to the three PHEV types (10, 20 and 40 miles of electric range) in each of the three electric sector scenarios (High CO_2, Medium CO_2, and Low CO_2 Intensity).

PHEVs have lower GHG emissions in all nine cases than either the conventional or the hybrid vehicles, ranging from a 40% to 65% improvement over the conventional vehicle to a 7% to 46% improvement over the hybrid electric vehicle.



Year 2050 comparison of PHEV GHG emissions from within the High CO_2, Medium CO_2, and Low CO_2 Intensity electric sector scenarios (12,000 miles driven per year)

EPRI Perspective

This report describes a study to explore the air quality impacts of large numbers of plug-in hybrid electric vehicles (PHEVs) in year 2030 using a combination of transportation-sector, electric-sector and atmospheric (air quality) models.

PHEVs represent an important technical step toward increased fuel efficiency, decreased emissions, and greater energy independence. EPRI has supported the development of PHEV technology and continues to support its deployment with collaborative R&D and analyses.

Policymakers, technology developers, and utility and environmental planners need objective and accurate information to make sound decisions about developing and deploying PHEVs in support of national energy and environmental policy. PHEVs offer the potential for reducing both emissions and fuel consumption, simultaneously addressing the issues of global warming and the nation's dependence on imported oil. Quantifying these benefits has proved challenging, however, and misinformation has circulated about the environmental performance of PHEVs.

The objective of this study was to evaluate the impact of PHEVs on key air quality parameters for a future-year scenario with substantial penetration of PHEVs in the U.S. light-duty vehicle fleet (passenger cars and light-trucks).

This study is one component of a comprehensive environmental assessment of PHEVs conducted in collaboration with the Natural Resources Defense Council (NRDC). A second component is a nationwide analysis of the nationwide impacts on air quality of a large PHEV fleet in the year 2030. Results of the air quality analysis are presented in an EPRI technical report, Environmental Assessment of Plug-In Hybrid Electric Vehicles, Volume 2: United States Air Quality Analysis Based on AEO-2006 Assumptions for 2030 (1015326).

Study findings will help support informed decision-making regarding PHEV development and deployment in support of national energy and environmental policy. Study results will also dispel misunderstandings about PHEVs and emissions—such as the common misunderstanding that PHEVs would worsen air quality due to emissions from electricity generation for battery charging.

NRDC Perspective

The Natural Resources Defense Council's purpose is to safeguard the Earth: its people, its plants and animals and the natural systems on which all life depends. The organization uses law, science, and the support of its members to promote solutions to our environmental challenges.

- Participation in this study does not imply NRDC endorses the power plant emission control assumptions in the air quality report. The study's air quality modeling and analysis are based on an assumption that regulatory caps govern NOx, SO_2 and mercury emissions during the study period, and that EPA rules do not change during the study time horizon. However, the actual situation is more complex—for example, a number of states have declined to participate in EPA's model cap-and-trade rule for mercury in favor of more stringent approaches. In addition, EPA's Clean Air Mercury Rule and Clean Air Interstate Rule (resulting in tighter NOx and SO_2 caps in the eastern U.S.) are currently being challenged in court. NRDC firmly believes that stronger emissions controls are necessary to protect human health. This study does not attempt to determine the adequate level of power plant controls or adequate levels of ambient air pollution and strives only to determine the specific impacts of large-scale PHEV penetration given the assumptions of the study.
- NRDC does not support trading off pollution benefits in some regions for pollution increases in others regions. NRDC believes that no areas or populations should be allowed to experience increases in air pollution exposures and that further emission controls from all sources are needed in order to protect public health. Consequently, NRDC supports more stringent emissions control requirements for the electric and transportation sectors, as well as other economic sectors.
- NRDC does believe that with sufficient emissions controls in place PHEVs have the potential to improve air quality and to substantially contribute to meeting our long term GHG reduction goals of 80% below 1990 levels by 2050.
- NRDC supports the introduction of PHEVs accompanied by substantial additional improvements in power plant emission rates. In areas where there are potential adverse impacts from air pollution as a result of PHEV charging, NRDC believes it is not appropriate to promote introduction until the public can be assured that air pollution will not increase.

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