EPRI ELECTRIC POWER RESEARCH INSTITUTE

NRDC THE EARTH'S BEST DEFENSE

Frequently Asked Questions

Environmental Assessment of Plug-In Hybrid Electric Vehicles

The Study

What was the motivation for this study?

Plug-In Hybrid Electric Vehicles (PHEVs) have the potential to contribute significantly to transportation efficiency with vehicles that can operate entirely on electricity generated by the nation's power grid. Reducing the nation's dependence on foreign oil may be good for national security—and moving from the gas pump to the electric outlet would dramatically reduce the cost of on-road transportation—but questions remain regarding the environmental consequences of displacing oil with electricity as a primary vehicle fuel. Thus, the study was initiated to comprehensively address two key questions related to environmental impacts.

- How will increased electricity demand from the transportation sector over time shape future electricity supply and its impact on the environment?
- How will changes in the electricity grid—including replacement of older power plants and incorporation of new technologies such as advanced coal, renewables, and other low-emitting sources—affect the environmental picture over time?

A number of studies have explored the environmental consequences but the results have been based on limited data from existing technologies in the transportation and electricity sectors. To answer these questions, the Electric Power Research Institute (EPRI) and the Natural Resources Defense Council (NRDC) conducted a comprehensive study to enhance our understanding of emissions scenarios of the electric and transportation sectors and how they might change in the future with wider deployment of PHEVs. The analyses assume that PHEVs become a dominant future automotive power-train technology.

Why did EPRI conduct two separate studies?

EPRI conducted two separate studies for two reasons:

- There were significant differences in the assumptions in the electric-sector models and analysis used to evaluate the impact of PHEVs on GHG emissions and the models and analysis used to evaluate the impact of PHEVs on air quality.
- The time horizons for evaluating the impacts on greenhouse gas emissions and on air quality are different.

What are the differences between the two electric-sector models?

The two models are conceptually similar in the way that they model the electric sector. The main differences are in scale and computational expense:

- National Electric System Simulation Integrated Evaluator (NESSIE), the electric sector model used in the greenhouse gas (GHG) emissions study, simulates the evolution of the U.S. electric sector—capacity and generation mix—and provides aggregate results based on North American Electric Reliability Corporation (NERC) electricity regions. This level of detail is sufficient to perform a greenhouse gas emissions analysis. In addition, the computational efficiency of the model allows the flexibility to perform the various simulations necessary to evaluate potential GHG impacts under different scenarios.

- The North American Electricity & Environment Model (NEEM) the electric sector model used in the air quality (AQ) study, simulates the evolution of the U.S. electric sector—capacity and generation mix—and provides results disaggregated down to individual units. This level of detail is necessary in order to allocate emissions in time and space to individual units of different generation technology. These emissions are then used by an atmospheric model to determine impacts on air quality, deposition and visibility, including understanding where and when chemical reactions that form smog and other pollution occur in the atmosphere.

Which atmospheric model was used to simulate air quality?

The U.S. Environmental Protection Agency's Community Multiscale Air Quality (CMAQ) model was used to simulate U.S. air quality in 2030 for the AQ study. This model incorporates meteorology and emissions from power plants, motor vehicles, and all other man-made and natural sources as input and simulates air quality over the United States accounting for chemical and physical transformations of pollutants in the atmosphere.

Which assumptions differ between the two studies?

The greenhouse gas study evaluates net GHG emissions impacts that would result from the widespread use of PHEVs in the United States. It constructs different scenarios based on different electric sector GHG emission intensities and PHEV market penetrations.

Given the computational expense associated with running an air quality model for the United States, the air quality study evaluates the impact of PHEVs for only one electric sector future. The air quality scenario mirrors the U.S. Department of Energy's 2006 Annual Electric Outlook (AEO)—the assumption commonly used in air quality studies. The analysis is performed in the absence of any policies or constraints on greenhouse gas emissions. This framework is appropriate for an air quality study because it removes any perceived bias in favor of PHEV adoption due to the implementation of GHG abatement technologies.

What are the time horizons in the GHG and AQ study?

The time horizon of analysis for the GHG emissions analysis extends to 2050. The time horizon for the air quality study extends to 2030. The principal impacts of air quality regulations passed in recent years extend to the years 2018 or 2020, making projections beyond 2020 uncertain. However, it was necessary to extend the air quality study to a year when PHEVs could be expected to make up a significant portion of on-road vehicles. The year 2030 was chosen as an appropriate balance between uncertainty in emissions constraints and PHEV market penetration.

It is noteworthy that the overall vehicle fleet in 2030 is less emissions-intense (in terms of VOC and NOx per vehicle mile traveled) and has fewer total emissions (in terms of total annual VOC and NOx emissions) for the transportation sector in 2030 than in 2018 or 2020. These characteristics are due to fleet turnover to notably less-emitting vehicles.

What are the similarities between the GHG and AQ analyses?

The transportation assumptions in the AQ study follow the progression of the sector in the middle-PHEV-penetration scenario of the GHG emissions study. All assumptions related to the performance and electricity demands of PHEVs are equivalent in the two studies.

The Results

What are the key results of the GHG study?

- Annual and cumulative GHG emissions are reduced significantly across each of the nine scenarios.
- Annual GHG emission reductions were significant in every scenario combination of the study, reaching a maximum reduction of 612 million tons in 2050 (high PHEV fleet penetration, low electric sector CO_2 intensity).
- Cumulative GHG emission reductions from 2010 to 2050 can be large, ranging from 3.4 to 10.3 billion tons.
- Each region of the country will experience reductions in GHG emissions from PHEV adoption.

What are the key results of the AQ study?

- In most regions of the United States, PHEVs result in small but significant improvements in ambient air quality and reduction in deposition of various pollutants such as acids, nutrients and mercury.
- On a population weighted basis, the improvements in ambient air quality are small but numerically significant for most of the country.
- The emissions of gaseous criteria pollutants (NOx and SO_2) are constrained nationally by regulatory caps[1]. As a result, changes in total emissions of these pollutants due PHEVs reflect slight differences in allowance banking during the study's time horizon.
- Considering the electric and transportation sector together, total emissions of VOC, NOx and SO_2 from the electric sector and transportation sector decrease due to PHEVs. Ozone levels decreased for most regions, but increased in some local areas. When assuming a minimum detection limit of 0.25 parts per billion, modeling estimates that 61% of the population would see decreased ozone levels and 1% of the population would see increased ozone levels.
- Mercury emissions increase by 2.4% with increased generation needs to meet PHEV charging loads. The study assumes that mercury is constrained by a cap-and-trade program, with the option for using banked allowances, proposed by EPA during the execution of the study. The electric sector modeling indicates that utilities take advantage of the banking provision to realize early reductions in mercury that result in greater mercury emissions at the end of the study time frame (2030).
- Primary emissions of particulate matter (PM) increase by 10% with the use of PHEVs due primarily to the large growth in coal generation assumed in the study.
- In most regions, particulate matter concentrations decrease due to significant reductions in VOC and NOx emissions from the transportation sector leading to less secondary PM.

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1 Regulatory caps are limits on the total emissions that the electric sector as a whole may emit during a year regardless of electricity demand. EPA distributes emissions allowances (the right to emit a unit of a pollutant) in an open market. Electric companies can trade allowances in a cap-and-trade system or choose to "bank" allowances for use in the future if they emit below their total emissions allowance

How could particulate matter concentrations improve in the PHEV scenario if PM emission increases from the electric sector are greater than the offsets in PM emissions from the transportation sector?

Particulate matter concentrations in ambient air are a combination of particles directly emitted by sources (primary PM) and particles formed due to chemical processes in the atmosphere (secondary PM). The offsets in NOx and VOC emissions from the transportation sector lead to a decrease in secondary PM formation. Although primary emissions of PM increase by 10% from the electric sector in the PHEV scenario, the combination of primary and secondary PM is less in the PHEV scenario.

How could mercury deposition decrease in the PHEV scenario if total emissions of mercury are capped under both scenarios?

Mercury deposition is influenced by emissions and by atmospheric chemistry. Chemical reactions cycle mercury from its elemental form to oxidized forms that can deposit more readily in rain or by contact with the Earth's surface. The lower levels of atmospheric ozone in the PHEV scenario cause more mercury to remain in the elemental form and thereby decrease the amount deposited on the ground surface.

Electric sector mercury emissions are assumed to be constrained by regulatory caps in this study. As a result, the small emissions increase observed is due to changes in allowance banking during the study's time horizon. In addition, 21 states are requiring reductions that are potentially more stringent than the model cap-and-trade program proposed by EPA (not included in this study). As a result, PHEVs cannot increase the U.S. contribution to the global mercury budget over the long term. Moreover, PHEVs serve to enhance the benefit of early banking as mercury emissions decline by the time these banked allowances are emitted.

Nitrogen deposition is discussed in the air quality report. Why is total nitrogen deposition important?

Total nitrogen deposition includes the deposition of oxidized nitrogen (e.g., nitric acid and nitrate) and reduced nitrogen (e.g., ammonia and ammonium). Nitrogen can adversely influence water quality by making toxic metals more available in biological systems. In addition, nitrogen increases the nutrient content of ecosystems; excess nutrients can lead to potential adverse impacts on vegetation. This can cause eutrophication of water bodies leading to hypoxic conditions that can impact ecosystems[2].

One estimate of the incremental electrical demand attributed to PHEVs is 6% in 2030. Is there sufficient transmission capacity in the United States to satisfy this increase?

Electricity demand in the United States is projected to grow by ~50% (1,931 MMWh, million megawatt hours) during the AQ study's time horizon (2006-2030), The additional load due to PHEVs increases gradually from negligible in 2010 to -~339 MMWh by 2030, less than 1/5 of the

[2] The USGS defines eutrophication at http://toxics.usgs.gov/definitions/eutrophication.html

- Eutrophication is a process whereby water bodies, such as lakes, estuaries, or slow-moving streams receive excess nutrients that stimulate excessive plant growth (algae, periphyton attached algae, and nuisance plants weeds). This enhanced plant growth, often called an algal bloom, reduces dissolved oxygen in the water when dead plant material decomposes and can cause other organisms to die. Nutrients can come from many sources, such as fertilizers applied to agricultural fields, golf courses, and suburban lawns; deposition of nitrogen from the atmosphere; erosion of soil containing nutrients; and sewage treatment plant discharges. Water with a low concentration of dissolved oxygen is called hypoxic.

incremental demand which is projected to increase from 2006 to 2030 in the absence of PHEVs. As a simplifying assumption in the AQ study, it was assumed that population growth and economic expansion would drive transmission expansion within the different electric sector regions of the United States. The study relied on the existing transmission grid to move electricity across different power pools.

Why does the electric-sector modeling show an appreciable amount of new coal-fired electric generation by 2030?

The air quality scenario is constructed to mirror the U.S. Department of Energy's 2006 Annual Electric Outlook (AEO). This is a common assumption used in air quality studies. The economic analysis is performed in the absence of any greenhouse policy or the prospect of any future policy. In the high-GHG-intensity electric-sector portfolio, the GHG emissions study includes some mild constraints to reflect generation capacity expansion in an uncertain regulatory climate for GHG emissions. This uncertainty does not exist in the AQ study because the AQ study is designed to conform with the 2006 AEO report. Thus, the AQ study shows a sizable increase in coal-fired generation.

However, as noted earlier, this framework is appropriate from an air quality study perspective since it avoids any perceived bias in favor of PHEV adoption due to the implementation GHG abatement technologies. Since computational limitations limit the number of scenarios explored in the AQ study, it is important to perform this AQ analysis of PHEVs in this framework.

Why were legislative initiatives, such as California's Global Warming Solutions Act of 2006 (AB 32) and California's Greenhouse Gas Performance Standards (SB 1368) or the Regional Greenhouse Gas Initiative (RGGI) of Northeastern and Mid-Atlantic States, as well as more stringent state-specific mercury rules, not included in the analysis?

In the 2005 Integrated Energy Policy Report (IEPR), the California Energy Commission recommended that the state "should specify a GHG performance standard and apply it to all utility procurement, both in-state and out-of-state, both coal and non-coal," but it was not until later that this standard was ratified into law as SB1368. Both AB 32 and SB1368 were signed by Governor Schwarzenegger during the execution of this study and were not included in the analysis because of a lack of specificity in the requirements of the law. Similarly, it was not until late 2006 that the states participating in RGGI developed and issued a model rule for the RGGI program or that states were required to submit their mercury plans to EPA. As a result, the study maintains a close similarity to AEO 2006.

Were any modifications to AEO 2006 implemented?

The most notable modifications to AEO 2006 include:

- The successful implementation of renewable portfolio standards, mandates and goals in Arizona, California, Colorado, Connecticut, District of Columbia, Florida, Illinois, Iowa, Maine, Maryland, Massachusetts, Minnesota, Montana, Nevada, New Jersey, New Mexico, New York, Pennsylvania, Rhode Island, Texas, and Wisconsin.
- Offset electricity demand as a result of California's Million Solar Roofs Initiative.

Did your analysis include biofuels such as ethanol or biodiesel?

We compare electricity as a transportation fuel only to standard gasoline and diesel fuels from petroleum. Biofuels were not included in the study.

There are numerous biofuel pathways either in production or under development. Many biofuel pathways are projected to have GHG benefits over gasoline or diesel from petroleum. It is important to understand which pathways will be used in the future and to what extent they will be used in order to quantify potential future GHG and other environmental benefits.

In order to better understand the environmental impact of biofuel use in the transportation sector, a similar environmental assessment of biofuel production, distribution and use—including greenhouse-gas, air quality, water quality and land-use impacts—would be required and is recommended. Such an assessment would be an important step in understanding the impacts of integrating biofuels into the U.S. transportation system.

Did your analysis consider hydrogen fuel cell vehicles?

The analyses did not consider hydrogen fuel cell vehicles. Hydrogen fuel cell vehicles are considered a long-term technology. It is also very difficult to forecast market shares of different (competing or complementary) vehicle technologies. There are also many unanswered questions regarding hydrogen production, distribution and storage that would significantly impact any environmental modeling.

Did your analysis include battery electric vehicles?

Battery electric vehicles (BEVs) were not considered. From a technical standpoint, it is reasonable to expect that a transportation future that contains PHEVs with up to 40 miles of electric range would almost certainly also contain BEVs. The GHG impacts of a single BEV could be easily calculated from any of the electricity scenarios in the GHG study. BEVs were not included in the nationwide fleet analysis as this would require speculating on BEV market share relative to PHEVs. BEVs generally have similar per mile GHG and energy consumption characteristics to PHEVs when running in the all-electric mode.

The relative impact of BEVs on air quality can be deduced from the perspective gained from the AQ study: BEVs, like PHEVs, would not cause significant increases in power plant emissions of SO_2, NOx, and mercury. Since BEVs always run with zero tailpipe emissions, they would serve to amplify the air quality benefits of electrifying transportation.

What is the effect of Vehicle-to-Grid (V2G) on the environmental impact of PHEVs?

There is tremendous interest in the interaction of PHEVs and the electricity grid. V2G is one of several technology concepts that would enable PHEVs to function as "distributed energy storage" for the electricity grid. The practical effect of this technology would be to allow greater shaping of the PHEV electrical load. At this time, we do not know enough about possible implementations of V2G to model their effect on the electric sector—however it is an excellent topic for future work in this area.

How soon will PHEVs be commercially available?

Several vehicle manufacturers have announced their intent to produce plug-in hybrid electric vehicles. General Motors has announced that two vehicles—the Chevrolet Volt and Saturn Vue will be available in the coming years as their first PHEV offerings. For the purposes of this study, we assume that PHEVs first enter the vehicle market in 2010.

How do your assumptions of PHEV market acceptance compare to the commercial success of Hybrids today?

In the GHG study, we looked at three different penetrations—low, medium and high. Low is a "conservative" estimate and medium assumes that the market forces that have caused the recent "surge" in continue and promote both higher adoption of HEV and PHEV technology. The high scenario assumes we see an adoption of the technology that is plausible but represents an extreme. Since we could only model one scenario in the AQ study, we chose the medium penetration. It is important to note that these are only assumptions of future market adoption that serve as bounding cases—other market penetration estimates may also be valuable to consider.

What are the peak load increases in the study? How can this be mitigated?

System capacity increase ranges from roughly 1% to 5% by 2050 in the different PHEV scenarios. This is a very modest number and is a fraction of normal load growth and capacity expansion in the electric sector. Intelligent charging and other technologies can be used to help ensure that charging is performed off-peak, minimizing the amount of new capacity needed.

What is left unanswered? What are EPRI's plans?

We have done the Air Quality study in the AEO-consistent case. Now we need to perform a similar study that takes into account climate-change and environmental regulations that have been passed since the study began (AB 32, SB 1368, RGGI, state-specific mercury controls). We also need to understand how different climate policy options impact the rate of adoption of PHEVs and how the electric and transportation sector may work together in an economy-wide framework. We refer to this phase as "Environmental Assessment Phase 2" and we are seeking partners and funders. It is also important to understand the environmental impacts of other complementary and/or competing fuels—such as ethanol, biobutanol (biogasoline), biodiesel and hydrogen—and technologies such as V2G. This would be the third phase of the Environmental Assessment work.

In addition, we are looking at regional impacts using higher resolution air quality modeling. We refer to this as "Region Specific Air Quality Analyses".

Finally, technology, science, economics, and environmental regulations affecting transportation and electricity change rapidly. The models used to simulate these change just as rapidly. Just as the IPCC performs an assessment of climate change in a regular fashion, this type of analysis should be repeated every 6-8 years in order to provide the best and most-current information to inform policy-makers, and all stakeholders.

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