John Voelcker’s article “How Green Is My Plug-In?” delves into the carbon impact of plug-in hybrid electric vehicles (PHEVs), and it generated quite a bit of discussion. After that article appeared in March 2009, IEEE Spectrum’s David Schneider spoke with Jeremy Michalek, an assistant professor of mechanical engineering and of engineering and public policy at Carnegie Mellon University (CMU). Michalek’s upcoming study in Energy Policy looks at the sizing of batteries for such cars; in it, he calculates that plug-in hybrids with large battery packs—like the 2011 Chevrolet Volt—may never save consumers any money.

The Electric Power Research Institute (EPRI) has a different view of the future than Michalek does. Here, in an interview with Voelcker, Mark Duvall, director of electric transportation at EPRI, explains the results of his organization’s detailed analyses of the environmental and energy impacts of PHEVs—which were conducted with the Natural Resources Defense Council (NRDC)—and relates some of the experiences developing models of the impact of plug-in hybrid technology.

IEEE Spectrum: What was your goal in doing the EPRI-NRDC study?

Mark Duvall: We wanted to conduct the first comprehensive study of the environmental impacts of plug-in hybrid vehicles—both for greenhouse-gas emissions and air quality. To really analyze these issues, you need sophisticated and detailed models of the electricity sector to understand which power plants would be used to generate the electricity to charge PHEVs—which were conducted with the Natural Resources Defense Council (NRDC)—and relates some of the experiences developing models of the impact of plug-in hybrid technology.

IEEE Spectrum: Did that study assess the costs of cutting carbon using plug-in hybrids?

MD: That’s very difficult to do for vehicle technologies. While transportation as a whole is a large emitter of greenhouse gases, each vehicle saves a very small amount of carbon (one liter of gasoline produces about 3 kilograms of CO₂; 1 gallon, about 11 kg). If you don’t get all of the costs exactly right—especially the purchase cost of the vehicle—you get really large variations in cost-effectiveness, all the way from saving money by cutting carbon to costs of US$ 1000 or more per ton of carbon. Our work indicates that PHEVs, once the technology matures and they attain volume production, can be manufactured and sold for a reasonable price and that owners can expect to save money over the useful life of the vehicle.

IEEE Spectrum: One area where you differed with the Carnegie Mellon study was the cost of batteries, which it pegged at $1000 per kilowatt-hour. How do you view that estimate?

MD: We agree that until battery costs reach some more reasonable level (for example, $500/kWh), no plug-in hybrid can save enough fuel to cover its higher production cost. However, we’ve done quite a lot of cost modeling. Once batteries drop to the $500/kWh range, our studies indicate that plug-in hybrids with 10, 20, and 40 miles of range will all save money over their useful life—and this was with gasoline at about $3 per gallon. If gasoline costs more, as many analysts seem to expect, then the savings increase.

IEEE Spectrum: When do you see batteries dropping to that level?

MD: We are seeing some indications that battery costs for high-volume orders may be...
cycles, I will need to replace the battery in just 28,000 miles. No one will be very happy with
technology can reach. If I buy a 7-mile PHEV and drive it exactly 7 miles between charge
but one that our research and testing in this area leads us to believe today's battery
For example, let's say I have a battery that lasts for 4000 deep cycles—a challenging goal,
trouble-free miles from a new car. The more frequently you charge and discharge a battery,
market research shows that vehicle owners expect the battery to last the life of the
MD: Absolutely. The electric motors, power electronics, and electric accessories are also
Again, there will be a robust and mature market for all types of PHEVs, EREVs, and even
whether we expect first-generation plug-in vehicles to offer. That cost is almost entirely
due to the limited volume and conservative approaches used by the automakers when
launching new technologies.
Once production volumes increase and the industry feels more certain about the real-world
performance of the batteries, we will likely see cost fall to $500/kWh and the
state-of-charge range rise to as much as 80 percent. Those changes will cut vehicle mass to
less than the most lightweight case in the CMU study. These factors really have to be
considered together, not separately, to get an idea of where things are headed.
Spectrum: What do you consider to be the most cost-effective way to displace gasoline in
U.S. transportation?
MD: There are numerous studies in this area. The answer is probably somewhat boring, like
driving less, driving slower, or introducing minimum tire-efficiency standards.
But reducing petroleum consumption to any reasonable level will require us to use every
technology we have that can be made cost-effective. Hybrids, plug-in hybrids, and electric
vehicles are just the options we need to develop if we are to have any hope of
making progress on this issue. But we don’t see them as competing with other
options—biofuels, public transit, et cetera—because we’ll need all of those as well.
Spectrum: Michalek’s advice to consumers was “Buy small, charge often.” What’s your
thought there?
MD: This is a terrible idea. Frequent charging of a smaller battery will wear it out very
quickly. Market research shows that vehicle owners expect the battery to last the life of the
car. This makes sense, considering that we’re now used to 100,000 to 150,000 relatively
trouble-free miles from a new car. The more frequently you charge and discharge a battery,
the shorter the time until you have to replace it.
For example, let’s say I have a battery that lasts for 4000 deep cycles—a challenging goal,
but one that our research and testing in this area leads us to believe today’s battery
technology can reach. If I buy a 7-mile PHEV and drive it exactly 7 miles between charge
cycles, I will need to replace the battery in just 28,000 miles. No one will be very happy with
that. In fact, we have market studies that show consumers would be unhappy.

But if I buy a 40-mile PHEV and drive it exactly 40 miles between charges, I'll have 160,000 miles on it when the battery wears out. And the difference in battery life is even greater, since a 40-mile battery will make a lot of trips of fewer than 40 miles, with correspondingly less discharge, whereas most drivers are likely to completely discharge a 7-mile battery on almost every trip.

One question I would add: Is it worthwhile to go past 40 miles of electric range? A little less than 80 percent of U.S. drivers travel fewer than 40 miles per day. Also, if you charge a Chevy Volt at work, it is roughly equivalent to a battery-only electric vehicle with an 80-mile range. Several years ago, we analyzed a PHEV with 60 miles of range and found the savings from 60 miles is not that much higher than 40 miles—unless you have a really long commute.

In real life, most of these vehicles will run on a mix of electricity and gasoline. Otherwise, they'd be electric vehicles! But it's vital to note that the smaller the battery is, the harder it becomes to make it last the lifetime of the car. That's why a plug-in with 7 miles of range probably won't offer a lot of electric-only range. It will operate in hybrid mode most of the time, blending gasoline and electricity. So it will drive a lot like your current hybrid, only with better fuel economy. If you want real electric range, even for around-town driving, you realistically need the equivalent of at least a 15- or 20-mile battery.

**Spectrum:** In less than two years, we will see first-generation plug-in hybrids available for sale in the United States. What are the biggest unknowns for future generations of plug-in technology?

**MD:** We are primarily concerned with how fast the market will grow. I would be happy with a growth rate similar to hybrid vehicles, which have reached a total of 1 million sales in the United States after eight years—though I would prefer we get there quicker. This will require lots of manufacturers entering the market, strong customer demand, and a variety of vehicles to choose from. I'm not worried about the vehicles themselves; they will be very, very good.

**Spectrum:** Any last comments?

**MD:** The real strength of the plug-in hybrid concept is that the battery can be sized to accommodate the daily driving patterns of most users. The data tell us that more than 70 percent of U.S. drivers cover fewer than 40 miles a day. There is no one "right amount" of electric range, because everyone has different needs and price sensitivities. Remember that when hybrids were first introduced, most analysts complained that none of them made economic sense. Now nearly all of them do. We expect the same thing to happen for plug-in hybrids with 10 to 40 miles of range.

In the end, people will buy plug-ins because they want them, and the most important thing automakers can do is give them reasons to buy them. It is more important to get well-engineered plug-in vehicles into production as soon as possible and get them out there than to worry about what amount of range is best.