Car-tastrophe

How federal policy can help, not hinder, the greening of the automobile

By Amy Kaleita, Ph.D.

PRI
PACIFIC
RESEARCH
INSTITUTE

Car-tastrophe

How federal policy can help, not hinder, the greening of the automobile

By Amy Kaleita, Ph.D.

Car-tastrophe
How federal policy can help, not hinder, the greening of the automobile
By Amy Kaleita, Ph.D.

January 2011

Pacific Research Institute
One Embarcadero Center, Suite 350
San Francisco, CA 94111
Tel: 415-989-0833/ 800-276-7600
Fax: 415-989-2411
Email: info@pacificresearch.org
www.pacificresearch.org

Download copies of this study at www.pacificresearch.org.

Contents

Acknowledgements

The author would like to thank all the organizations and individuals who contribute to PRI's environmental studies. Without their financial support this study could not have been completed. The author would like to acknowledge Ken Green of the American Enterprise Institute and Joel Schwartz for their formal review of this study. Any remaining errors or omissions are the sole responsibility of the author. As the author of this study has worked independently, her views and conclusions do not necessarily represent those of the board, supporters, or staff of PRI.

Introduction

With the upcoming introduction of plug-in vehicles such as the Chevy Volt and the Nissan Leaf, interest and enthusiasm for electric vehicles (either fully electric, or plug-in electric with a supplemental internal combustion engine) are gaining steam. A March 2010 *Consumer Reports* poll indicated that more than a quarter of consumers are likely to consider a plug-in electric car the next time they are shopping for a new vehicle (7 percent claimed they were "very likely") – a surprisingly high number given the fact that these vehicles were not even readily available at the time of the poll. In a 2009 Rasmussen poll, 40 percent of those surveyed indicated they are at least somewhat likely to actually buy an all-electric car within the next decade, while 21 percent said it was somewhat likely that the *next* car they buy will be all-electric.

Much of the interest is based in large part on the perceived potential of these vehicles to decrease the "environmental footprint" of driving a car in America, with much of the focus on greenhouse gas emissions. The transportation footprint is significant. Approximately one-third of U.S. emissions of carbon dioxide (CO_2), the most common of the greenhouse gases credited with contributing to climate change, come from the transportation sector as a whole (all vehicles whose primary purpose is to transport people or goods). More than 90 percent of that is associated with burning of petroleum fuel (USDOE, 2009).

For much of this country, cars are the primary mode of personal transportation and are all but certain to remain so, at least for the foreseeable future.

The United States does not have the population density to support widespread pubic transportation for intercity travel, and only some urban areas can support efficient intra-city public transportation. Therefore, for much of this country, cars are the primary mode of personal transportation and are all but certain to remain so, at least for the foreseeable future.

Finding ways to "green" the American car culture is thus of interest to many people. Unfortunately, many policies designed to accomplish that may well wind up doing the exact opposite. This paper explores the environmental implications of several commercially available vehicle and fuel types, and identifies where policies could be improved to result in net benefits to Americans. The paper ends with some guiding principles for limiting the true environmental footprint of driving in America.

Gas stations are ubiquitous and offer fast refueling. Charging stations, on the other hand, are not, and do not.

Today, consumers have a multitude of vehicle options, from what is under the hood to what – if anything – is in the tank. Assessing the environmental impact of the variety of choices is not simple.

Plug-in hybrid electric vehicles (PHEVs) operating in parallel can use either an on-board battery, charged with electricity from the grid, or an engine that burns liquid fuel. Fully electric vehicles (EVs) use only the charged battery for power. PHEVs also have an advantage in their internal combustion engine (ICE), which give such vehicles a range (how far the car can go before it must be refueled and/or recharged) similar to that of conventional vehicles.

Vehicles that travel fewer than about 30 miles per day account for 60 percent of daily passenger vehicle miles in the United States (US DOT 2004). The limited range of fully electric vehicles, therefore, would perhaps not be a major problem for many drivers. The *Consumer Reports* poll indicated that the median range desired by consumers is 89 miles, while nearly half of respondents would be satisfied with a range less than 75 miles (29 percent would even be satisfied with a range of less than 49 miles).

It is difficult to generalize about the operational characteristics of the variations of PHEVs and EVs currently or soon to be on the market, because they are quite different. The PHEV Chevrolet Volt, set to debut in late 2010 (early 2011 in many markets), has a lithium-ion battery and, according to GM, a typical electric range of 25-50 miles "depending on terrain, driving technique, temperature, and battery age." (GM, 2010) A 10-hour charge time, depending on climate, is required on standard 120-volt power, or down to four hours on a dedicated 240-volt line, according to Chevrolet's Volt Web site (http://www.chevrolet.com/volt/).

The cars themselves have no emissions of greenhouses gases or air pollutants, but generating the electricity that charges the battery usually does.

The fully electric Nissan Leaf has only a lithium-ion battery and has a range of about 60-140 miles, according to Nissan's testing (Automotive News, 2010). About 20 hours are then required to recharge the vehicle on 120-volt power, or about seven hours on a 240 volt line (http://www.nissanusa.com/leaf-electric-car/faq/list/charging). Toyota has announced plans to offer a plug-in hybrid Prius in 2012, with a small lithium-ion battery and a commensurately small all-electric range of 13 miles.

For all plug-in vehicles, hilly terrain, aggressive driving, stop-and-go traffic, and hot or cold temperatures will limit the electric range to the shorter end. A driver in bumper-to-bumper traffic in Phoenix in mid-summer with the air conditioner on will certainly not get the same range as a driver in leisurely countryside driving outside Sacramento in autumn. While conventional vehicles also get variable miles per gallon of fuel depending on the situation, the implications of the wide range of electric distances are more troublesome for EVs (and for PHEVs if the driver wants to do most driving in electric mode). For one thing, gas stations are ubiquitous and offer fast refueling. Charging stations, on the other hand, are not, and do not. Nissan's FAQ on charging the Leaf indicates that even at a 480-volt "quick-charging station," a charge would take 30 minutes.

> Plug-in hybrids offer surprisingly little GHG reductions over conventional vehicles in places where coal is the dominant electricity source.

The variability in actual range performance also makes it difficult to assess the overall impact of PHEVs and EVs on the environmental footprint of the car, because it depends very much on the expected electric range of the vehicle. Furthermore, in accounting for the impact of PHEVs and EVs on the environment, one must also consider that in electric mode, the cars themselves have no emissions of greenhouses gases or air pollutants, but generating the electricity that charges the battery usually does.

GHG emissions from different vehicle power types

A 2008 study (Samaras and Meisterling, 2008) attempted to capture these dynamics in a full life-cycle assessment of PHEVs, compared to conventional internal combustion engine vehicles (ICEVs) and regular hybrids (Figure 1). Using greenhouse gas emissions as a metric, the researchers found that plug-in hybrids offer surprisingly little GHG reductions over conventional vehicles in places where coal is the dominant electricity source, particularly for longer-range electric operation. Furthermore, where coal is dominant, PHEVs significantly increase net GHG emissions over hybrid vehicles. In order for PHEVs to offer any significant advantages over conventional engines or hybrids, low-CO_2-emissions electricity must predominate.

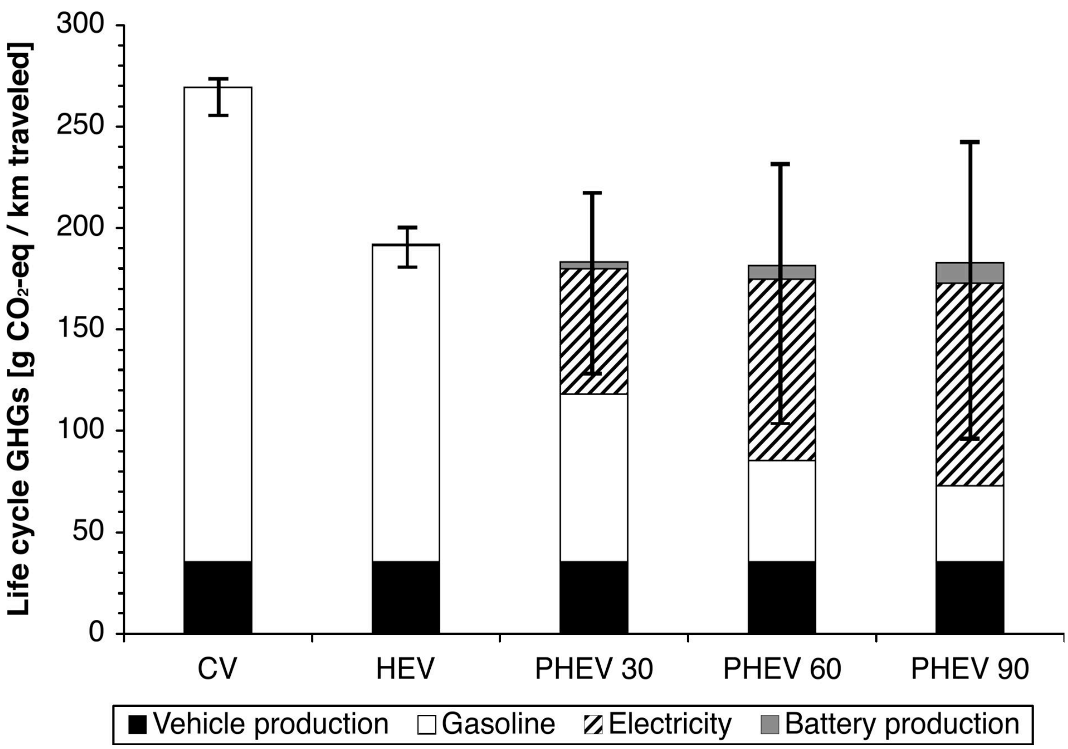

Figure 1. A life cycle GHG emission (g CO2-eq/km) of conventional vehicles (CVs) with 30 mpg fuel economy, hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs) with all-electric ranges of 30 km (19 mi), 60 km (37 mi), and 90 km (56 mi), and 45 mpg fuel economy for the liquid fuel operation. For the PHEV vehicles, the current GHG-intensity of the US electric power portfolio is used to determine the vehicle life cycle emissions, and uncertainty bars represent changes in total emissions under carbon-intensive electricity (where coal is the dominant electricity source) or low-carbon electricity (where wind, hydro, nuclear, or coal with carbon capture or sequestration are significant energy sources). From Samaras & Meisterling, 2008.

Other researchers have come to the same conclusions. A study at Carnegie Mellon determined that with today's average U.S. electricity portfolio, PHEVs are only cost-competitive and more environmentally sound than other options when they are short-range vehicles charged every 20 miles or less (Shiau et al., 2009). In an environmental and economic comparison of various vehicle types, including conventional vehicles, hybrids, and electric vehicles, Canadian researchers found that electric cars are only beneficial when the electricity is generated on-board or when the car is charged with electricity generated from no- to low-carbon sources (Granovskii et al., 2006). Such sources include nuclear, hydroelectric, wind, solar, and geothermal, or coal with carbon capture or sequestration.

In only 12 states is more than 40 percent of the total electricity generated from low-carbon sources.

EVs, PHEVs and the electricity grid

According to the U.S. Department of Energy, such low-carbon electricity sources are atypical. In 2008, 48 percent of the megawatt-hours of electricity generated in the United States were from coal, and an additional 21 percent from natural gas (EIA 2010). Regions where coal-fired generators dominate electricity production have the highest rates of CO_2 emissions per megawatt-hour, and while natural gas has about 45 percent lower carbon content than coal, natural gas is not a low-carbon electricity source either.

For a regional breakdown, figure 2 shows the percent of total electricity generated in each state from coal. Coal is less than 40 percent of the electricity source in only 20 states and less than 30 percent in only 16 states.

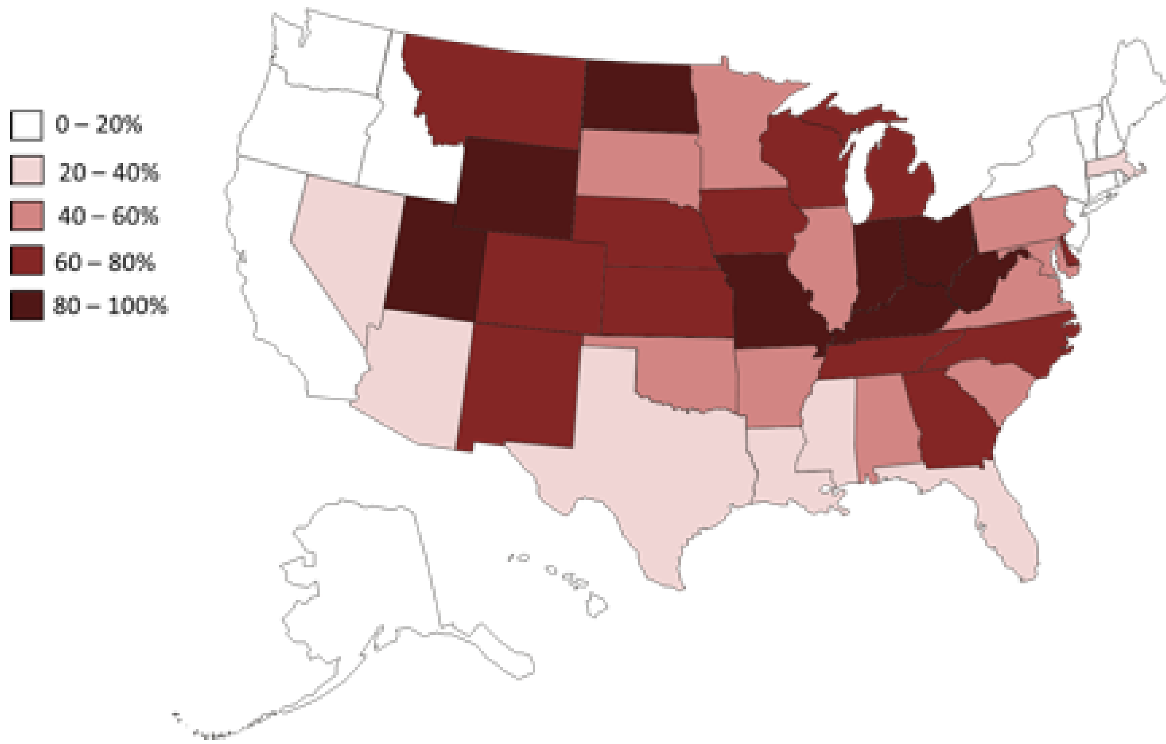

Figure 2. Percent of energy generated within each state that comes from coal. Data from the U.S. Department of Energy (EIA 2010).

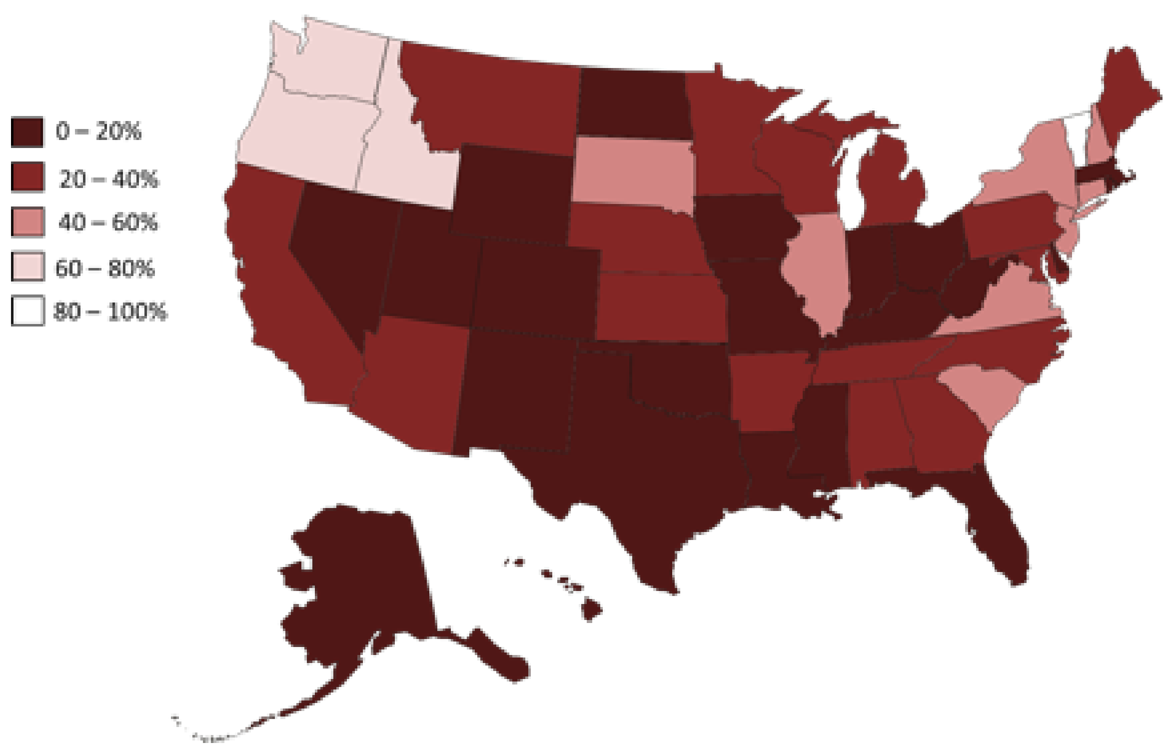

Figure 3. Percent of energy generated within each state that comes from low-carbon sources (nuclear, hydroelectric, wind, solar, and geothermal). Data from the U.S. Department of Energy (EIA 2010).

In fact, in only 12 states is more than 40 percent of the total electricity generated from low-carbon sources, as shown in figure 3. Certainly, there is room for development of more widespread low-carbon electricity generation but it is not at all clear how exactly that should be accomplished. Carbon capture and sequestration at the coal plants is a possibility, but only small-scale capture or sequestration pilot projects exist right now, and it remains to be seen whether this approach will be cost-effective.

If plug-in vehicles should become wildly popular, at some point increased electricity generation capacity would have to follow.

Wind and solar are not likely to comprise significant and reliable sources in the near term, and at this time are not economically competitive without significant price supports in the form of federal, state, and local incentives and subsidies. Hydroelectric power is limited to places with sufficient natural resources for surface water storage and flow capacity. Nuclear power, of course, is not without its critics.

But if plug-in vehicles should become wildly popular, at some point increased electricity generation capacity would have to follow, particularly in regions where electricity generation is already near capacity or where it is unlikely that all charging will occur during off-peak hours (Hadley and Tsvetkova, 2009). Given the availability and feasibility of generation sources, it's unlikely that all the increased capacity would come from no- or low-emission sources. In one detailed study of the hourly impact of widespread PHEV deployment on the western U.S. electricity grid (California and the Pacific Northwest – currently a region with relatively low carbon intensity), researchers found that compared to the baseline case of no PHEV deployment, PHEVs led to increased grid emissions of greenhouse gases, non-methane total organic compounds, and carbon monoxide (Jansen et al., 2010).

Incentivizing EVs, PHEVs, and hybrids

Clearly, plug-in cars are only "green" for a limited number of situations, considering both regional electricity mix and driving habits. Nevertheless, this has not prevented policymakers from rushing headlong into incentivizing widespread adoption of electric vehicles.

The International Energy Agency recommends incentives to encourage people to purchase PHEVs or fully electric plug-ins (IEA, 2009). Domestically, President Obama has stated a goal of putting 1 million plug-in hybrids on the road by 2015. The 2009 American Recovery and Reinvestment Act included tax credits for consumer purchases of EVs and PHEVs (US DOE, 2010), and up to $2 billion in research and development funds (Pew Center, 2009). Up to $400 million has been set aside for transportation electrification demonstration and deployment projects (Pew Center, 2009).

Despite repeated research showing that the benefits of PHEVs are, for the most part, limited to small-capacity vehicles, the U.S. Department of Energy has entered a partnership, up to $10 million, with Navstar to develop PHEV school buses, and the U.S. House of Representatives (through H.R. 3246) set aside more than $1 billion toward development of medium- and heavy-duty PHEVs. Any investment in electric vehicles, however, will not reduce GHG emissions in much of the country where coal is the primary energy source, and would result in little return overall compared to the already-popular hybrid vehicles.

Plug-in cars are only "green" for a limited number of situations, considering both regional electricity mix and driving habits.

Hybrid vehicle buyers have likewise been the recipients of considerable incentives. While the federal tax credits phase out for a particular manufacturer once it has sold 60,000 eligible vehicles, several hybrids still have such incentives, including the BMW ActiveHybrid 750i ($900) and the Nissan Altima Hybrid ($2,350). Many states offer additional incentives in various forms, such as rebates, tax credits and deductions, sales tax waivers, fee waivers, and access to carpool lanes even when driving solo. Some employers, such as Timberland and Google, offer incentives to their employees for purchasing hybrids.

Though these incentives have promoted purchases of hybrids to some extent, the incentives are probably costlier to provide than other emissions-reduction mechanisms. For one thing, researchers have attributed only 6-27 percent of hybrid purchases in the United States to tax incentives (e.g. Galleger and Muehlegger 2010, Beresteanu and Li 2010). Canadian researchers reached similar conclusions for that country's hybrid purchases (Chandra et al., 2010).

The bulk of hybrid purchases are actually attributable to high gasoline prices and/or social preferences – those consumers thus received incentives for purchases they were going to make anyway. The high percentage of "free riders" significantly decreases the cost-effectiveness of incentive programs.

Hybrids are also pricier than their conventional ICE counterparts, and those premiums may be relatively expensive for the level of emissions reductions which hybrids achieve. In a comparison of the hybrid Toyota Prius and the conventional Toyota Corolla, researchers found that the Prius does indeed have lower pollutant and CO_2 emissions, but is not cost-effective – there are less costly ways to achieve the same emissions reductions (Lave and MacLean, 2002).

At higher speeds (approaching 60 miles per hour), hybrids' fuel consumption and the resulting emissions are similar to conventional vehicles.

As with PHEVs, hybrids are most effective at reducing emissions under specific circumstances – fairly small cars operating at low speeds. For example, a 2008 study of the Toyota Prius and the Honda Civic hybrid demonstrated that hybrids provide the most benefit under urban driving conditions with very low speeds typical of stop-and-go traffic. At higher speeds (approaching 60 miles per hour), hybrids' fuel consumption and the resulting emissions are similar to conventional vehicles (Fontaras et al., 2008).

Fueling conventional vehicles

When it comes to conventional internal combustion engine vehicles (ICEVs), a major question today is whether biologically derived fuels can provide environmental benefits compared to fossil fuels. In the United States, the primary source of biofuels is currently corn-based ethanol, followed by biodiesel made from soybeans. Other energy crops, such as grasses like switchgrass and miscanthus, may be viable energy feedstocks, though much research remains to be done on how to optimize production of these crops and how to make them cost-effective for generating fuel. Other biological sources, such as algae, are still in the research phase as fuel sources.

Are biofuels an answer to decreasing the environmental impact of passenger vehicles? In the life-cycle comparison of PHEVs, conventional vehicles, and hybrids discussed above, the researchers concluded that if conventional vehicles were fueled by E85 (85 percent ethanol blend, with the ethanol produced from cellulosic feedstocks), conventional vehicles would have substantially lower net GHG emissions than PHEVs under the current electricity generation portfolio (Samaras and Meisterling, 2008). However, on the whole, there is substantial debate among scientists regarding the net GHG impact of biofuel production.

On the one hand, the fuel source itself generates no net carbon emissions when burned. Biomass gets its carbon from the atmosphere in the first place and returns the carbon to the atmosphere when it is burned to produce energy. In this sense, it is "carbon neutral." However, when the entire life cycle is considered, several prominent studies (e.g. Pimentel and Patzek, 2005) have concluded that biofuel production is not significantly more carbon-neutral than gasoline as a liquid fuel, and in fact may consume more energy in the production than it generates. Critics contend that those studies have used outdated information on typical fuel economy of farm vehicles, and other outdated assumptions. When updated information is used, biofuel production appears to generate less overall emissions (e.g. Kim and Dale, 2005).

However, not all biofuels are created equal. Per acre, different "energy crops" require different inputs and processing, and can generate different amounts of energy as a fuel (liquid or otherwise). The energy return on ethanol from sugar cane, for example, is significantly higher than that from corn – one study, for instance, found the fuel energy per acre from sugar cane to be more than three times that of corn (Sims et al., 2006). The same is true for conventional diesel and biodiesel.

For instance, Australian researchers found that for biodiesel production, palm oil can produce up to an 80 percent saving in emissions, provided it is sourced from older plantations, rather than from plantations cleared from forested areas (Beer et al., 2007). And sometimes it is not an energy crop at all that provides the best return. The Australian report noted that in that country, the best source for biodiesel (that with the lowest net lifecycle emissions of GHGs and air pollutants) was used cooking oil.

At the same time, a study of European Union legislation to promote the expanded use of biodiesel found that biodiesel generated from rapeseed (canola) resulted in the same GHG emissions as conventional diesel (rapeseed-derived biodiesel is the leading biofuel in the EU). The study concluded that planting trees on the rapeseed land would do significantly more to reduce overall GHG emissions (Johnson and Heinen, 2007).

In the near term, biofuels derived from agricultural crops may do more harm than good.

Of course, greenhouse gasses are not the only vehicle emissions. Vehicles also emit smog-related compounds and other potential air pollutants – although since the 1960s, the efficiency of vehicles, and reductions in emissions, have improved many times over, because of advancements in both fuel technology and vehicle technology. It is not clear that biofuels are a net gain on that front, either. For example, simulations by a Stanford atmospheric scientist found that while E85 vehicles reduce atmospheric levels of two carcinogens, benzene and butadiene, they increase that of two others, formaldehyde and acetaldehyde. Furthermore, the study found that expanded use of E85 would significantly increase ozone, a key component of smog (Jacobson, 2007).

However, GHG and air pollutant emissions are only part of the environmental impact of liquid fuel generation. In the case of biofuels, evidence is mounting that at least in the near term, biofuels derived from agricultural crops may do more harm than good (for example, see Groom et al., 2008, for an overview of environmental and ecological impacts of agricultural biofuels). Biofuel mandates increase the land area used to grow crops, increasing applications of fertilizers and herbicides and therefore posing a threat to water quality. The use of agricultural residues like corn stalks and other biomass left behind after harvest as a source (feedstock) for biofuels will accelerate soil erosion and oxidation of soil carbon – not only compromising soil fertility, but also raising CO_2 emissions from the soil. In regions where irrigation is necessary, expanded or intensified agricultural production may further stress water resources.

Incentivizing biofuels

These concerns have not stood in the way of government endorsement of biofuels, regardless of source. In 2005, the federal government introduced the first Renewable Fuel Standards, which required that by 2012 at least 7.5 billion gallons of renewable fuel must be blended into motor-vehicle fuel sold in the United States. Many states, including California, followed suit by launching their own plans for renewable fuel mandates. The program was expanded in 2007 and again in 2010, more than doubling the 2012 biofuel requirement in motor-vehicle fuel to 15.2 billion gallons per year, and increasing the volume of renewable fuel required to be blended into transportation fuel to 36 billion gallons by 2022. In October 2010, the EPA announced it would approve a fuel blend of 15 percent ethanol (up from 10 percent) in gasoline for vehicles from the 2007 and later model years.

To help accomplish this, as of this writing the domestic ethanol industry receives a 45 cent-per-gallon "Volumetric Ethanol Excise Tax Credit" (VEETC) – at an annual cost to taxpayers of between $5 billion and $6 billion – as well as a 54 cent-per-gallon protective tariff that prevents lower-cost Brazilian ethanol (produced from sugar cane) from being competitive in the United States. While both are set to expire at the end of 2010, the industry and the U.S. Department of Agriculture are advocating their extension. In October 2010, U.S. Secretary of Agriculture Tom Vilsack announced that the government will resume subsidies to farmers to produce non-food crops that can be converted to biofuels.

The EPA proposed a scheme that addressed only tailpipe emissions, not net emissions from powering the vehicle.

No policies currently in place address the environmental and ecological consequences of expanded biofuel production.

Some research even suggests that there may be a better use of bio-based fuels than liquid applications. A 2009 study published in *Science* found that generating electricity from biofuel crops is considerably more energy efficient – and potentially more carbon efficient – than using them to produce liquid fuel (Campbell et al., 2009). The researchers noted that bioelectricity used for battery-powered vehicles would deliver an average of 80 percent more miles of transportation per acre of crops than generating ethanol for ICEVs, while also mitigating double the greenhouse gas emissions.

If all the variations in vehicle type and fuel source and the associated environmental impacts seem confusing, that's because they are. The federal government has unfortunately done little to help consumers sort out this morass. Current EPA standards for estimating the fuel economy of a car don't make sense for electric vehicles – but that doesn't mean the cars are infinitely efficient. And when trying to come up with new-car labels that allow for cross-comparison of hybrids, ICEVs (including flex-fuel vehicles that may run on E85, or vehicles running on a 10 percent ethanol blend), PHEVs, and EVs, the EPA proposed a scheme that addressed only tailpipe emissions, not net emissions from powering the vehicle. This type of assessment heavily favors EVs and PHEVs (which have no tailpipe emissions when operating on battery power), despite the fact that the overall emissions impact may or may not be an improvement over other vehicle types.

No policies currently in place address the environmental and ecological consequences of expanded biofuel production.

Recommendations

Overall, the automobile option with the smallest environmental footprint is the idealized situation of using clean energy to charge a high-performance battery for small-distance city drivers. It remains unclear, however, what energy is the "cleanest" at the lowest cost, all things considered. Even for longer-distance drivers with a charged battery supplemented by an internal combustion engine burning the most environmentally friendly fuel, it remains to be seen what, exactly, that fuel is. The ideal situation is far from the current reality – and creating that situation will require significant investments in research and development into new and innovative technologies, and perhaps significant changes in infrastructure.

Until such technological breakthroughs are realized, and until the energy sector has a different complexion than it does today, promoting electric vehicles could actually cause more harm than the perceived good it provides.

Therefore, policies related specifically to vehicle fuel or power today and in the foreseeable future should have the following guiding principles:

- *Outcomes are more important than products.* As exciting as the technology may be, electric vehicles are not universally helpful; in many situations they are inappropriate and lead to minimal environmental benefits at best, and negative impacts at worst. Until and unless the energy sector is less reliant on high-carbon sources, there should be no government incentives and pushes to expand consumer purchases of these vehicles.

- *Renewable fuel policy must incorporate a holistic approach.* Carbon emissions from the car are not the only environmental concern related to producing and burning liquid vehicle fuel. Many biofuels – notably, the most common biofuels in the United States, sourced from corn and soybeans – can have significant negative environmental impacts. The current renewable fuel standards and goals thus pose threats to overall environmental health. These policies seem based on the assumption that biofuels are uniformly beneficial, but that is not the case. Renewable fuel standards should not promote environmental degradation in ways besides carbon emissions only.

- *Government investment needs to spur technological development, not simply entrench and institutionalize first-generation efforts.* Biofuel subsidies, for example, may create a new energy sector that, rather than being viable as a self-sufficient industry, remains largely reliant on subsidies. Although many policymakers have noted that biofuel subsidies and protections should be phased out over time, the history of entrenched subsidies in the United States suggests that phase-outs will always remain a plan for some time in the future – they are rarely implemented. This serves only to tie up funds that might otherwise be available for other energy and automotive innovation.

Both biofuels and electric vehicles are highly incentivized by federal actions; yet, the environmental benefits of both remain questionable. Encouraging innovation and continued technological development will be more effective in the long run at addressing the environmental footprint of American automobiles than government programs that essentially mandate specific approaches.

References

Automotive News. 2010. *Nissan Leaf has 100-mile range – give or take 40%.* http://www.autonews.com/apps/pbcs.dll/article?AID=/20100621/OEM05/306219974/1429#ixzz164bXc6QN (verified 19 November 2010).

Beer, T., T. Grant, and P. Campbell. 2007. *The greenhouse and air quality emissions of biodiesel blends in Australia*. CSIRO. Available from http://www.csiro.au/files/files/phim.pdf (verified 11 October 2010).

Beresteanu, S. and G. Li. In press (2010). Gasoline prices, government support and the demand for hybrid vehicles in the US. *International Economic Review*.

Campbell, J.E., D.B. Lobell, and C.B. Field. 2009. Greater transportation energy and GHG offsets from bioelectricity than ethanol. *Science*. 324(5930): 1055-1057.

Chandra, A., S. Gulati, M. Kandlikar. 2010. Green drivers or free riders? An analysis of tax rebates for green vehicles. *Journal of Environmental Economics and Management*. 60: 78-93.

Consumer Reports. 2010. *Shocking results: Survey reveals what consumers want from electric cars.* http://blogs.consumerreports.org/cars/2010/03/consumer-reports-electric-car-buying-survey.html (verified 19 November 2010).

Fontaras, G., P. Pistikopoulos, and Z. Samaras. 2008. Experimental evaluation of hybrid fuel economy and pollutant emissions over real-world simulation driving cycles. *Atmospheric Environment*. 42: 4023-4035.

Gallagher, K. and E. Muehlegger. In press (2010). Giving green to get green? Incentives and consumer adoptionof hybrid vehicle technology. *Journal of Environmental Economics and Management*.

Granovskii, M., I. Dincer, and M.A. Rosen. 2006. Economic and environmental comparison of hybrid, electric, and hydrogen fuel cell vehicles. *Journal of Power Sources.* 159: 1186-1193.

Groom, M.J., E.M. Gray, and P.A. Townsend. 2008. Biofuels and biodiversity: Principles for creating better policies for biofuel production. *Conservation Biology*. 22(3): 602-609.

GM. 2010. *Chevrolet Volt Milestone Timeline.* http://publish.media.gm.com/content/product/public/us/en/volt/tech/timeline/_jcr_content/par/sectioncontainer_1/par/download/file.res/Volt%20Milestone%20Timeline.doc (verified 19 November 2010).

Hadley, S.W. and A Tsvetkova. 2009. Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional

Power Generation. *The Electricity Journal*. 22(10): 56-68.

IEA. 2009. *Electric and Plug-in Hybrid Vehicle Roadmap*. Available from http://www.iea.org/papers/2009/EV_PHEV_brochure.pdf (verified 11 October 2010).

Jacobson, M.Z. 2007. Effects of ethanol (E85) versus gasoline vehicles on cancer and mortality in the United States. *Environmental Science & Technology*. 41(11): 4150–4157.

Jansen, K.H., T.M. Brown, and G.S. Samuelsen. 2010. Emissions impacts of plug-in hybrid electric vehicle deployment on the U.S. western grid. *Journal of Power Sources*. 195: 5409-5416.

Johnson, E., and R. Heinen. 2007. Petroleum diesel vs. biodiesel: The race is on. *Chemistry & Industry*. April 23, 2007.

Kim, S. and B. Dale. 2005. Life cycle assessment of various cropping systems utilized for producing biofuels: Bioethanol and biodiesel. *Biomass and Bioenergy*. 29(6): 426-439.

Lave, L.B., and H.L. MacLean. 2002. An environmental-economic evaluation of hybrid electric vehicles: Toyota Prius vs. its conventional internal combustion engine Corolla. *Transportation Research Part D.* 7: 155-162.

Pew Center on Global Climate Change. 2009. *Key Provisions: American Recovery and Reinvestment Act.* http://www.pewclimate.org/docUploads/Pew-Summary-ARRA-Key-Provisions.pdf (verified 19 November 2010).

Pimentel, D., and T.W. Patzek. 2005. Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower. *Natural Resources Research.* 14(1): 65-76.

Rasmussen Reports. 2009. *40% Likely To Buy An All-Electric Car In Next 10 Years*. http://www.rasmussenreports.com/public_content/lifestyle/general_lifestyle/august_2009/40_likely_to_buy_an_all_electric_car_in_next_10_years (verified 19 November 2010).

Samaras, C., and K. Meisterling. 2008. Life cycle assessment of greenhouse gas emissions from plug-in hybrid vehicles: Implications for policy. *Environmental Science & Technology*. 42(9): 3170-3176.

Shiau, C.-S.N., C. Samaras, R. Hauffe, J.J. Michalek. 2009. Impact of battery weight and charging patterns on the economic and environmental benefits of plug-in hybrid electric vehicles. *Energy Policy*. 37: 2653-2663.

Sims, R.E.H., A. Hastings, B. Schlamadinger, G. Taylor, and P. Smith. 2006. Energy crops: current status and future prospects. *Global Change Biology*. 12: 2054–2076.

U.S. Department of Transportation. 2004. *2001 National Household Travel Survey*. DOT: Washington, DC.

United States Department of Energy, Energy Information Administration. 2009. Data available at http://www.eia.doe.gov/environment.html (verified 19 November 2010).

United States Department of Energy, Energy Information Administration. 2010. *Annual Energy Outlook 2010 with Projections to 2035.* http://www.eia.doe.gov/oiaf/aeo/arra.html (verified 19 November 2010).

About the author

Amy Kaleita, Environmental Studies Policy Fellow at the Pacific Research Institute, is assistant professor of agricultural and biosystems engineering at Iowa State University. Dr. Kaleita earned a B.S. in agricultural engineering from Penn State University and an M.S. from the University of Illinois in civil engineering, with an emphasis on environmental hydrology. She also earned a Ph.D. from the University of Illinois in agricultural engineering, with an emphasis on agricultural technology development for environmental conservation.

Dr. Kaleita's publications for PRI include *Is Your Food Making the Planet Sick?; The Way in Which We Produce our Food*: *The Impact of Genetically Modified Crops on the Environment*; *Go with the Flow: Why water markets can solve California's water crisis; Sense and Sequestration: The Carbon Sequestration Cycle Explained*, and *Hysteria's History: Environmental Alarmism in Context*. She also writes PRI's monthly Environmental Notes column.

Statement of Research Quality

The Pacific Research Institute is committed to accurate research and, to that end, submits all new PRI studies for review by a minimum of two researchers with expertise in the subject area, including a minimum of one external expert. To adjudicate any unresolved difference, deemed reasonable and substantive, between an author(s) and a reviewer, PRI maintains a Research Review Board (RRB). The RRB has final and determinative authority, and includes the following scholars:

Professor Robert Barro, Harvard University
Professor William Boyes, Arizona State University
Professor Steve Globerman, Western Washington University
Professor Jay Greene, University of Arkansas
Professor James Gwartney, Florida State University
Professor Eric A. Hanushek, Stanford University
Professor David Henderson, Naval Postgraduate School (Monterey)
Dr. W. Lee Hoskins, former president, Federal Reserve Bank of Cleveland (retired)
Professor Ronald W. Jones, University of Rochester
Professor Lynne Kiesling, Northwestern University
Professor Edward Lopez, San Jose State University
Professor Ross McKitrick, University of Guelph (Canada)
Professor Sandra Peart (Dean), University of Richmond
Professor David Schmidtz, University of Arizona
Professor Paul Zak, Claremont Graduate University

As part of its commitment, the Institute guarantees that all original factual data are true and correct to the best of our knowledge and that information attributed to other sources is accurately represented. If the veracity of any material fact or reference to an independent source is questioned and brought to the Institute's attention with supporting evidence, the Institute will respond in writing. If an error exists, it will be noted on the Institute website and in all subsequent distribution of the publication, which constitutes the complete and final remedy under this guarantee.

About Pacific Research Institute

The Pacific Research Institute (PRI) champions freedom, opportunity, and personal responsibility by advancing free-market policy solutions. It provides practical solutions for the policy issues that impact the daily lives of all Americans, and demonstrates why the free market is more effective than the government at providing the important results we all seek: good schools, quality health care, a clean environment, and a robust economy.

Founded in 1979 and based in San Francisco, PRI is a non-profit, non-partisan organization supported by private contributions. Its activities include publications, public events, media commentary, community leadership, legislative testimony, and academic outreach.

Education Studies

PRI works to restore to all parents the basic right to choose the best educational opportunities for their children. Through research and grassroots outreach, PRI promotes parental choice in education, high academic standards, teacher quality, charter schools, and school-finance reform.

Business and Economic Studies

PRI shows how the entrepreneurial spirit—the engine of economic growth and opportunity—is stifled by onerous taxes, regulations, and lawsuits. It advances policy reforms that promote a robust economy, consumer choice, and innovation.

Health care Studies

PRI demonstrates why a single-payer Canadian model would be detrimental to the health care of all Americans. It proposes market-based reforms that would improve affordability, access, quality, and consumer choice.

Environmental Studies

PRI reveals the dramatic and long-term trend toward a cleaner, healthier environment. It also examines and promotes the essential ingredients for abundant resources and environmental quality: property rights, markets, local action, and private initiative.